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ANALYSIS OF THE SUITABILITY OF VISUAL DESIGN OF ENERGY CONVERSION MEDIA WITH THE COGNITIVE CHARACTERISTICS OF JUNIOR HIGH SCHOOL STUDENTS BASED ON MULTIMEDIA LEARNING PRINCIPLES

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Abstract

Visualization of procedural science material such as energy conversion is necessary to represent invisible energt chages, however its effectiveness depends on compatibility with the student's cognitive characteristics. This study analyze the suitability of the design of energy conversion media based on coherence, segmenting, signalung and spatial contiguity and their implications for junior high school students' cognitive load. This study uses a quantitative descriptive approach with a content analysis method. Data is collected through direct observation of all visual elements of the media, including layout, text, color, visual markers and sequence of information. The analysis instrument was compiled based on a synthesis of literature on multimedia learning and cognitive load. Results show consistent application of segmenting, signaling and spatial contiguity consistently, however the application of coherence is still weak due to the use of irrelevant decorative elements. These findings show that the success of visualization in science learning is not only determined by the presence of animations, but also depends on the suitability of the design with the cognitive characteristics of students. This study recommends the elimination of irrelevant decorative elements and maintaining the integration of the principles of segmenting, signaling and spatial contiguity in the development of science learning media in junior high schools.

Keywords: *Visual Design; Multimedia Learning; Cognitive Load.*

INTRODUCTION

Fields of science such as Natural Sciences (IPA) generally contain abstract concepts that cannot be observed directly through the sense of sight, such as the process of energy change, chemical reactions or the movement of particles. This shows the need for help to represent these abstract concepts in the form of visualizations that can be seen so that students can understand the interactions between components and processes that occur in the concepts they are learning (Jaeger et al., 2021). Energy conversion media such as solar energy into electricity through solar panels, water energy into electrical energy through turbines or wind energy into electrical energy through windmills, helping students understand the stages of energy transformation (Handayani et al., 2021; Yudhistira et al., 2022).

Research by Hochberg et al. (2020) shows that the use of Multiple external representation (MER) such as tables, graphs and diagrams are useful in reconstructing students' understanding of physical phenomena, especially on concepts involving motion and energy changes. In line with this, the study of Becker et al. (2020) proves that dynamic visualization of matter allows students to understand the concept of causal relationships between the position, speed and acceleration of an object, which is similar to the need to understand the flow of energy that occurs in energy conversion events. Therefore, it is very important in designing visualization media that can assist students in connecting their understanding gaps between concrete and abstract phenomena.

Meanwhile, on the other hand, the suitability of the design with the cognitive characteristics of students is one of the important factors for the success of the application of visualization in learning. According to Piaget, students in the age range of 12-15 years (junior high school) generally have cognitive development that is in the transition phase from concrete operations to formal operations, so that the capacity of Working Memory students are still limited. In theory Cognitive Theory Multimedia Learning (CTML), Students has limited memory capacity in receiving new information. Working memory It is only able to accommodate a few pieces of information before the information is lost, so that when the information exceeds its capacity, it will occur Strange. Cognitive Load which hinders the process of long-term knowledge formation and storage in students (Mayer, 2024).

In addition to limited memory capacity, junior high school students are also easily distracted. When a medium displays less relevant information such as excessive decorative elements or unstructured presentation of material, it can divert students' concentration from focusing on the material to focusing on less essentials. This results in an increase in Extraneous cognitive load that is, a condition in which cognitive load does not contribute to the achievement of learning goals (Castro-Alonso et al., 2021). In more depth, junior high school students also have developing thinking skills where students are not fully able to do abstract reasoning and reconstruct the information as a whole. Thus, in designing the visualization of learning materials, it is not only important to aesthetics but also needs to consider Working Memory and The potential for distractions to appear in accordance with the student's cognitive development is intended to optimize intrinsic, extraneous and germane cognitive load (Jaeger et al., 2017).

However, in practice in the educational environment, there are still learning visualization media that do not pay attention to the principles of multimedia learning properly which has the potential to cause cognitive problems, as a result of which learning is not achieved. Some of the problems that often arise are: (1) dense, excessive visualizations increase Extraneous cognitive load (Jaeger et al., 2017); (2) excessive decorative elements violate coherence, distracting from main information (Castro-Alonso et al., 2021); (3) Separate text and images vailate spatial contiguity, causing split attention (Jaeger et al., 2017; Becker et al.,2020); (4) Complex material is presented simultaneously without potentially burdensome pauses Working Memory students, segmenting is needed (Castro-Alonso et al., 2021); (5) Unclear flow hinders understanding of dynamic phenomena, such as arrows, colors or highlighting is recommended (Jeger et al., 2017; Castro-Alonso et al., 2021).

Based on these five message design problems, it is important to know the main role of visual design in science learning. According to Jaeger et al. (2021) in their study, visuals play a role in representing concepts to make it easier for students to reconstruct phenomena that cannot be observed directly. Some of the main functions of visuals are: (1) simplification of complex information; (2) indicators of spatial and temporal relationships between elements; and (3) guide students' attention to the crucial points of the subject matter. In order for these functions to really work in supporting the achievement of learning objectives, visual design must take into account the limitations of students' memory by applying the principles of cognitive load theory. Cognitive Load Theory (CLT) presented by Sweller identified three types of cognitive load that affect learning effectiveness, namely intrinsic, extraneous and Germane. Intrinsic loads are related to the complexity of the material being studied, extraneous loads are related to loads that arise as a result of poor instructional design and germane loads are related to the loads prepared for the knowledge formation process. Thus, visualization will help reduce Cognitive Load during the learning process.

In the context of multimedia learning, the management of the three cognitive loads is adjusted to the characteristics of student information processing (Mayer, 2024). Thus, it is important to ensure that the principles of multimedia design are not only visually appealing, but also play a role in supporting the effectiveness of students' information processing (Çeken & Taşkın, 2022). Based on various multimedia learning principles, there are four principles of multimedia learning that are relevant in analyzing the suitability of the visual design of energy conversion media with the cognitive characteristics of junior high school students, namely Coherence Principle, segmenting principle, signaling principle and Spatial contiguity principle.

Therefore, this study aims to analyze the suitability of the visual design of energy conversion learning media using the four principles of multimedia learning, identify forms of violations of the four principles, analyze the implications of incompatibility with the cognitive load of students and provide recommendations for improving the visual design of energy conversion learning media in accordance with the cognitive characteristics of junior high school students.

METHODS

This study uses a qualitative descriptive approach with a content analysis method (Content Analysis). This method was chosen based on the purpose of the research, which is to analyze and describe visual messages applied in energy conversion learning media. Krippendorff (2004), that content analysis is a research technique that can be replicated to draw valid conclusions from the text to the context that needs to be researched. In the context of this study, the "text" in question is all the visual elements contained in the visualization media analyzed.

The object of this research is an energy conversion visualization media that contains a dynamic visual representation (animation) of the change of solar, water, and wind energy into electrical energy. The visualization of the scientific process is a consideration for the selection of media to be studied because it contains various relevant visual elements analyzed using the principle of multimedia learning. In addition, accessibility to all visual elements and information presentation structures allows for an in-depth analysis process. The units of analysis in this study include visual scenes, animation sequences, relationships between text and images, visual markers, information layouts as well as static and dynamic visual elements that represent the energy conversion process.

The data in this study are all elements contained in the energy conversion visualization media including Layout, text, images, colors, visual markers, sequence of information. The data is collected through direct observation of media displays. Each piece of media is observed to identify visual design characteristics related to the principles of multimedia learning. The analysis instrument was synthesis from literature studies on multimedia learning and cognitive load in science learning, identifying the visual characteristics that are consistently recommended visual characteristic, then grouped into coherence, segmenting, signaling, spatial contiguity and Cognitive Load (Table 1). The table is the author's guide in identifying and evaluating the suitability of visual elements in the observed media.

Table 1. Energy Conversion Visualization Media Suitability Analysis Indicator

Principle	Indicator	Literature Policy
Consistency	1. Display only visual elements that are relevant to the energy conversion process. 2. There are no decorative or animated images without a pedagogical function. 3. The text/narrative contains only essential information, not exaggeration. 4. There are no distracting seductive details.	Jaeger et al., 2017; Castro-Alonso et al., 2021; Al Atiyat, 2018

Segmenting	1. The energy conversion process is broken down into 2–4 logical stages. 2. Each stage is presented in a separate segment (slides/pages/sequences). 3. There are pauses or markers of transfer between segments. 4. Users can control the speed, repeat, or skip segments.	Castro-Alonso et al., 2021; Becker et al., 2020; Hochberg et al., 2020; Al Atiyat, 2018
Signaling	1. There are arrows, lines, or markers of the direction of the energy flow. 2. Colors/highlights are used consistently to emphasize important components. 3. Titles/markers help with onboarding at each stage. 4. The animation shows a sequence of staged processes with temporal markers.	Jaeger et al., 2017; Castro-Alonso et al., 2021; Dervić et al., 2019; Xie et al., 2017; Al Atiyat, 2018; Peeters et al., 2023
Spatial contiguity	1. The labels/text are placed directly next to the components described. 2. The function explanatory text is close to the component in the diagram. 3. Step instructions are placed close to the relevant diagrams/animations. 4. Related information can be viewed simultaneously without excessive scrolling.	Jaeger et al., 2017; Castro-Alonso et al., 2021; Becker et al., 2020; Dervić et al., 2019; Al Atiyat, 2018; Peeters et al., 2023

The data analysis technique through four stages of analysis consists of identifying visual media elements, categorization based on multimedia learning principles, interpreting the suitability of the cognitive characteristics of junior high school students and analyzing the implications for Cognitive Load. Results of the analysis guided visual accuracy assessment and design recommedations.

RESULTS

Overview of Energy Conversion Visualization Media

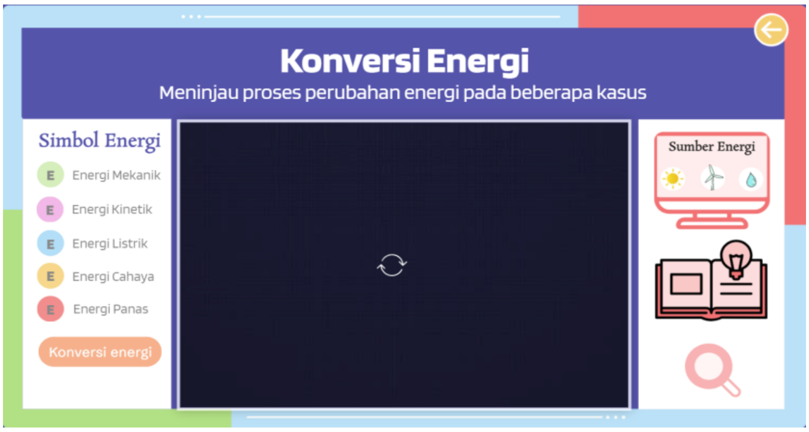

Figure 1. Initial Display of Energy Conversion Visualization Media

The media presented material on the conversion of energy from three different sources, namely solar energy, water energy and wind energy into electrical energy. The media display centers on the canvas as the main area to show the simulation of energy conversion. The media also provides interactive features in the form of control buttons for users such as energy conversion buttons, refresh buttons, back buttons, cross buttons. Through two-dimensional animation, the media can visualize the flow of water, windblown leaves and turbine rotations. To clarify the flow of the energy conversion process, the media utilizes the E symbol with a specific color to represent the change in the type of energy that moves dynamically from one component to another.

Coherent Principle Analysis

The visual findings of the energy conversion media show that the entire page has a pastel background (green, blue, pink) as a frame, as well as decorative elements on the right side such as a book icon with an incandescent lamp, a magnifying glass and a monitor screen that frames the main energy source (sun, water, wind). While on the right side there is an Energy symbol (E) with various color codes. On the solar energy conversion animation page there is an image of the sun with a yellow light effect, solar panels, electric generator batteries and incandescent lamps that emit yellow light. On the wind energy conversion animation page, there is an image of a moving leaf depicting the movement of the wind and turning a windmill, a battery as an electricity generator, an electric tower and an electrically powered house. On the water energy conversion page there are pictures of water taps that run water, water turbine wheels connected to generators, incandescent lamps that emit yellow light.

The results of the analysis showed that the existence of colorful backgrounds and less essential decorative elements such as book icons and incandescent lamps were not in accordance with the principle Consistency because it has the potential to distract students and increase Cognitive Strangers. Meanwhile, the narrative text in pop-up magnifying glass, sun and light emitting light, animated moving leaves, rotating windmills, flowing water, rotating turbine wheels are in perfect accordance with the principle Consistency because it displays information relevant to the energy conversion process.

Segmenting Principle Analysis

The findings show that the energy conversion process presented by the media is divided into 3-4 dynamic stages. 3-stage solar energy conversion, 3-stage wind energy and 4-stage water energy which then in each conversion process is followed by a pop-up that appears from the magnifying glass icon which contains a summary of the energy conversion process that occurs. All media pages also provide user control buttons in the form of *Refresh* to repeat the animation and cross buttons to close the pop-up.

The results of this analysis show that the energy conversion visualization media applies the principles of segmentation well, starting from dynamic stages to control settings by students that allow students to regulate their learning speed.

Signaling Principle Analysis

Figure 2. The Use of Visual Markers in the Energy Conversion Process

The findings show that the media applies the signaling principle through the use of the letter E symbol which is equipped with a specific color code. The symbol E with green means mechanical energy, pink for kinetic energy, blue for electrical energy, orange for light energy and red for heat energy. These symbols move dynamically following the flow of energy change indicating the type of energy involved in the ongoing energy conversion process. In addition, there is also a text title at the top of the pop-up to emphasize the energy conversion process, such as the Conversion of Solar Energy to Electrical Energy. The results of this analysis have implications for Cognitive Load where the movement of symbols and colors automatically directs the student's focus to important information that is able to lower Strange and maximize germane cognitive load.

Analysis of the Principle of Spatial Contiguity

Figure 3. Implementation of Spatial Contiguity

The visual findings of the energy conversion media show that the E symbol appears and precisely moves over the relevant components, such as the blue colored electrical symbol that is right on top of the wire, the green symbol of mechanical energy is on top of the water turbine and so on. On the other hand, the explanatory text pop-up at the end of each energy conversion session displays concise information that can be viewed directly on a single screen without the need to do much Scrolling. The results of this analysis show that the media has applied the principle of Spatial contiguity. This plays a role in lowering Extraneous cognitive load Because the students' eyes do not need to go back and forth to match the information in the simulation that is happening with the information of the energy that occurs in the process.

DISCUSSION

The results of the study show that the energy conversion visualization media against the four principles of multimedia learning applying segmentation, signaling and spatial contiguity is the most dominant and consistently applied. The application of segmentation is one of the most consistent principles applied in energy flow visualization media. The presentation of a gradual energy conversion animation equipped with user control is in line with the principle of segmenting which emphasizes on breaking complex information into simpler parts to avoid cognitive load (Castro-Alonso et al., 2021). This is also suitable for junior high school students who have limited working memory capacity , which allows students to process information optimally at each stage before moving on to the next stage (Mayer, 2024). Research by Becker et al. (2020) is in line with this, that segmentation is very effective for materials with high interctivity elements such as energy conversion because it reduces working memory load.

The results of the signaling analysis showed the application of the use of the symbol E which is consistent with color coding to indicate the flow of the energy conversion process. These findings are in line with a study by Dervic et al. (2019) that the principle of signaling acts as a visual marker such as color and movement to direct students' attention. This is suitable for junior high school students who tend to have visual attention that is easily distracted, so this marker helps to be the focus of students in processing information. Previous research has shown that cueing through color and movement can reduce extraneous cognitive load because students don't have to manually search visuals to find relevant information (Xie et al., 2017).

The results of the spatial contiguity analysis showed that all animations displayed on the energy visualization media placed labels, symbols and explanatory text directly near the relevant components. These findings are very consistent with the application of the principle of spatial contiguity which aims to avoid split attention effects (Jaeger et al., 2017). When explanations and related images are spatially separate, students have difficulty understanding the material because they have to go back and forth to divide the focus to match the information with several different sources of information. Research by Castro-Alonso et al. (2021) shows that the application of spatial integration by using relevant text and images is efficient in improving student learning outcomes. With a layout like this, junior high school students will focus their attention on understanding the relationship in the energy conversion process without being distracted by attempts to search for visual explanations.

The combined application of the principles of segmenting, signaling and spatial contiguity together in the media of visualizing energy conversion support students' information processing. The gradual presentation of information accompanied by the use of visual markers and integrated text placement helps students understand the relationship between the stages of the energy conversion process in a more targeted manner. This is in line with the research of Schneider et al. (2021) that the combination of these three principles helps reduce the burden on working memory because students' attention is directed to relevant visual elements at each stage of learning. Thus, the integration of the principles of segmenting, signaling and spatial contiguity is suitable to be applied to science materials that are processual in nature such as energy conversion.

Although visual analysis media shows consistent application of all three principles of multimedia learning, the application of the principle of coherence is the weakest. The results of the analysis showed that the media displayed decorative elements such as colorful backgrounds and book icons with incandescent lights had no relevance to the material. In fact, according to Jaeger et al. (2017) in their study on the principle of coherence, all elements that are not relevant to learning objectives should be eliminated to reduce visual distractions in students. In line with that, Çeken and Taşkın (2022) in their research emphasized that irrelevant decorative elements can inhibit the mental formation of student models so that they have the potential to increase extraneous cognitive load, especially in junior high school students whose visual attention tends to be easily distracted.

The findings regarding the weak application of the principle of coherence show that visual appeal in learning media is not always directly proportional to cognitive effectiveness. Research by Désiron & Schneider (2024) emphasizes that the use of decorative elements can not only improve aesthetics, but can also distract students from key information if used excessively. Especially in junior high school students who have visual attention that is easily distracted, elements that are not relevant to the material have the potential to increase extraneous cognitive load so that the concept understanding process becomes less optimal (Bali et al., 2026). Thus, in developing science learning media, it is very important to consider the effectiveness of information processing in addition to considering attractive visual appearances.

Based on the findings of the analysis of energy conversion visualization media that has been carried out, it shows that the success of visualization in science learning is not only determined by the existence of animations and illustrations, but also depends on how the information is processed according to the design principles and cognitive characteristics of students. This is in line with Mayer's (2024) research which shows that structured and directed visual presentation can help students process information in learning.

CONCLUSION

This study of energy conversion visualization media has integrated the principles of segmenting, signaling and spatial contiguity well through the presentation of the energy conversion process in stages, the use of consistent visual markers, and the appropriate layout of texts, images and symbols to help students understand the energy conversion process shown by the media. However, coherencen principle is poorly applied due to irrelevant bacground and decoartive elements. This shows that the success of visualization in science learning depends on how the information is processed according to the design principles and cognitive characteristics of students. The incompatibility of visual presentation with learning objectives has the potential to make students experience extraneous cognitive load that hinders students' processing of information on the material.

Based on the results of the research, there are several things that need to be considered in the development of science learning media. First, a balance in visual appeal and the effectiveness of information processing through the application of multimedia learning principles. Second, the use of segmenting, signaling and spatial contiguity in procedural science materials needs to be maintained, while the use of irrelevant elements is minimized to reduce distractions. On the other hand, this study has limitations, namely it only focuses on the visual aspect of the media and does not directly measure the perception of cognitive load of junior high school students. Therefore, researchers are then advised to analyze various types of science learning media such as video and audio and conduct direct tests on junior high school students to see and find out the effectiveness of media in managing cognitive load.

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