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From Prompt to Pedagogy: Designing AI-Generated Science Comics Through ChatGPT to Employ Critical Thinking Skills

Aris Rudi Purnomo*[1], Prima Vidya Asteria[2], Muhamad Rois Abidin[3], Arqoma Nurveda Carreza[4], Suhailee Sohnui[5]
[1,2,3,4]Universitas Negeri Surabaya, Surabaya, Indonesia
[5]Chiang Mai University, Chiang Mai, Thailand
[1]arispurnomo@unesa.ac.id, [2]primaasteria@unesa.ac.id, [3]roisabidin@unesa.ac.id, [4]arqomacarreza@unesa.ac.id, [5]suhailee.s@cmu.ac.th
*arispurnomo@unesa.ac.id

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ABSTRACT
Background/purpose. In science learning, critical thinking skills are essential indicators for delivering deep learning. In doing so, teaching alone is not enough to make students acquire the skills. Therefore, teachers need media such as e-comics for use in their classrooms. In this study, we examine the use of ChatGPT 4.0 as a tool for automatically generating visual representations from prompts to bring out the essence of critical thinking skills.
Materials/methods. This study used Design and Development Research (DDR), including needs analysis, design, and development, and expert validation. The instruments were a questionnaire and a validation rubric. The data were analyzed descriptively, considering the number of questionnaire items selected. A validation rubric is used to gain expert judgment over the quality of the e-comic developed using ChatGPT.
Results. The findings indicate that "Cells" (67%) and "Pollution" (65%) were perceived as the most difficult topics. The developed e-comic was rated highly valid in terms of content, while minor improvements were suggested for media aspects such as engagement and visual consistency. The study also resulted in an AI-Prompted Comic Design Framework consisting of five stages, namely, need analysis, narrative design, prompt engineering, AI-based visual generation, and expert validation.
Conclusion. The study demonstrates that ChatGPT can be effectively used to develop structured, visually consistent e-comics for science learning. The proposed framework provides practical guidance for integrating AI into instructional media design to support students' critical thinking. However, the effectiveness of the e-comic in improving learning outcomes requires further investigation in future studies.

1. INTRODUCTION

Critical thinking is a fundamental competency in science learning and a core competency of deep learning, as it enables students to engage in complex problem-solving and informed decision-making (Hidayati & Sinaga, 2019; Saputri, Sajidan, & Rinanto, 2018). Gibson (2016) asserts that the skills include higher-order cognitive operations such as interpretation, analysis, evaluation, inference, explanation, and self-regulation, which are

strongly correlated to Ennis' work. In the digital era, however, the development of critical thinking skills remains critically insufficient as many students still operate at low cognitive levels (George, Baskar, & Srikaanth, 2024; Sujatmika et al., 2024). In line with that, Jou, Lin, and Wu (2016) found that students are unable to summarize a great deal of information provided online from different angles. In addition, data show that critical thinking skills in deductive reasoning, inference-making, and argument evaluation have decreased by an average of 10-15% in the general population over the last 30 years (George et al., 2024).

Although teachers have used various digital learning resources, such as videos, slides, and online content, these media tend to promote passive consumption, in which students receive information without actively engaging in analysis or evaluation (Kim, Kim, & Barnett, 2021; Lamon et al.). Additionally, the abundance of information in digital environments often leads to cognitive overload, making it difficult for learners to identify relevant concepts and construct meaningful understanding (Sweller, 2010). Digital materials are also frequently fragmented and lack narrative coherence, which hinders students' ability to connect ideas and develop deeper conceptual insight (Brame, 2016). These limitations, then, highlight the need for more structured and engaging instructional media, such as digital comics, which integrate visual and narrative elements to promote critical thinking.

To facilitate students' acquisition of critical thinking skills, teachers can use learning media such as comics. According to Sari et al. (2020), comics can improve critical thinking in terms of mathematical representation and creative thinking. Furthermore, the narrative and visual appeal of comics significantly boost students' motivation and engagement with scientific concepts, enabling them to elaborate on their understanding (Azizi & Fauzan, 2020; Faria et al., 2024; Landherr, 2019). Unfortunately, teachers face challenges in creating comics because representing stories visually requires technical skills such as drawing and design (Abrori et al., 2024). Also, crafting compelling, educational narratives in comics requires creativity and storytelling skills, which many teachers find challenging to balance with scientific accuracy and student engagement (Pujaanti & Isnah, 2023). These factors diminish teachers' confidence in developing innovative materials for science learning (Canuto, 2024; Matuk et al., 2021; Yu & Sumayao, 2022).

To address the aforementioned challenges, this article examines the use of prompts in ChatGPT to assist educators in crafting their own multimedia learning materials for classroom use. The application provides chat features for discussion, allowing teachers to adjust the flow of the comic story and scientific content to adapt (Audichya & Saini, 2023; Fiialka et al., 2024). Notably, the feature is enabled by Natural Language Processing (NLP), which can integrate multifaceted information to generate intended products, resembling human-human interaction (Kishor et al., 2024; Santhosh et al., 2023). In academic practice, ChatGPT is widely used to assist with writing, including the creation of teaching materials (Fiialka et al., 2024). So far, however, for image creation, ChatGPT is often used alongside other applications to make

changes aligned with teachers' desired goals (Panchal et al., 2024). This indicates a gap in AI-generated visual pedagogy, particularly in designing coherent, pedagogically meaningful visual narratives such as comics that explicitly support critical thinking. Moreover, the effectiveness of AI-generated output depends heavily on how prompts are constructed. However, there is a lack of structured frameworks to guide educators in developing prompts that ensure consistency, relevance, and alignment with critical-thinking processes.

To address this gap, this study provides evidence that ChatGPT can be used to visualize the story, particularly in terms of critical-thinking features. Subsequently, its practices can elevate the way ChatGPT and other chatbot applications support science learning. So, the research questions for this study are as follows: 1) How can the design of the storyline explicitly convey critical thinking aspects? 2) What are the strategies for prompting to produce consistent and relevant stories? Moreover, 3) how do the experts say in the validation stage to ensure the accuracy of content and pedagogical aspects? By addressing these research questions, this article contributes to the development of a structured AI prompting framework for generating science-based digital comic storylines that explicitly embed the critical thinking process. Therefore, it bridges the gap between AI technology and visual pedagogy in science education.

2. METHODS

This study used Design and Development Research (DDR) to develop a comic for learning from the basic needs of science teachers. The design of DDR enables researchers to identify real needs in teaching and learning, develop instructional media based on the needs, and evaluate their quality through expert validation before implementation. Hence, this design is suitable for developing AI-generated e-comics that integrate pedagogical and technological aspects. The design consisted of three phases: needs analysis, design development, and expert validation (Jaya & Zaharudin, 2021). The initial phase focused on identifying what media teachers need for classroom use and what content or materials should be conveyed in the media to convey difficult concepts. To do so, a four-item questionnaire was administered to biology teachers from eight schools in Surabaya, East Java, Indonesia. To assess critical thinking skills, this study employed Ennis' theory, which comprises five indicators. Afterward, the second phase used the results of the first phase to design the comic, starting with the storyline, storyboard, prompts, and layout. Both the storyline and the storyboard were developed using a structure of contextual phenomena to capture students' attention, followed by a solution, explanation, and elaboration. The sequential stage of the comic's storyline was adapted from Netedu (2024), which presented the story from the perspective of emotional entities through images and narration. From the storyboard, the narrative version of the comic was transformed into visual elements, with ChatGPT 4.0 prompts structured around gender, physical characteristics, uniforms, expressions, backgrounds, and image style. The final

step in the research is to obtain expert judgment on the comic's development. There are two experts involved, that is, experts in content and media for learning, to assess the relevancy of the story and the style with respect to critical thinking and the appropriate reader age group, considering psychological maturity.

The instruments employed were questionnaires and a validation rubric. The questionnaires were designed to evaluate the perceived difficulty of teaching the subject matter and the preferred learning media. The validation process for the content used a five-item rubric assessing the core concept, cognitive level (based on Bloom's Taxonomy), contextual problem, critical-thinking propensity, and contribution to the discussion. The rubric for media encompassed eight items categorized into three aspects: pedagogy, technical, and aesthetic. The data was categorized into quantitative and qualitative types. The quantitative data were analyzed descriptively by examining the percentage of selected items represented by the teachers. The other quantitative data point was the validation score, which ranged from 1 to 4. Experts with relevant backgrounds in content and media determined the validity. The comic was categorized as valid if the scores of 3 and 4 were above 70% of all items to be assessed (Damopolii et al., 2021). Qualitative data are used to support the results of quantitative data analysis.

It should be noted that this study is limited to the design, development, and expert validation stages. The efficacy of the developed e-comic in improving students' critical thinking skills has not yet been empirically tested in classroom settings. Therefore, future research needs to focus on using either an experimental or a quasi-experimental design to evaluate the extent to which the e-comic enhances critical thinking skills.

3. RESULTS AND DISCUSSION

This part shows what happened as a result of the comic media development process conducted using the ChatGPT app. The research findings follow a structured research flow that includes needs analysis, development, and expert validation.

3.1 Need Analysis

The comic's story starts with the context or real-life problem, then moves on to the solution, explanation, and more details. It serves to clarify the chronological exposition of scientific concepts presented in Table 1. The materials were chosen based on responses to a survey of biology teachers that asked which materials were the hardest to teach. They need media to get scientific information to students.

Table 1. Subject matter perceived as challenging, preserving media for instructional and learning purposes.

No.	Topic	Perceived as difficult
1	Immune system	42%
2	Transport system	55%
3	Cells	67%

No.	Topic	Perceived as difficult
4	Pollution	65%

Based on the questionnaire results in Table 2, Teachers ranked "Cells" as the most difficult subject at 67%, followed by "Pollution" (65%), "Transport System" (55%), and "Immune System" (42%). The finding suggests that teachers identified difficulties from the perspective of the abstract concepts and contextual phenomena.

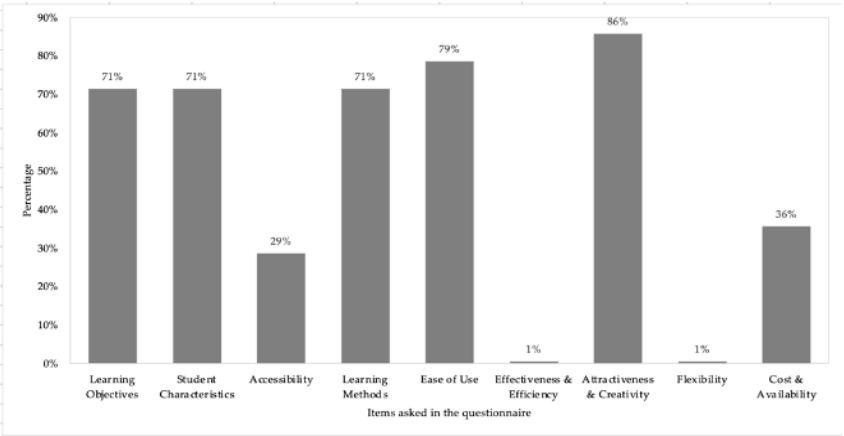


Figure 1. Preferred criteria among teachers for media of learning

Figure 1 shows that the teachers considered several important factors when choosing instructional media. These included the learning goals, students' needs, media availability, learning style, cost, and ease of use. Attractiveness and Creativity were the most important factors for 85.7% of respondents when deciding what instructional media to use. After that, Ease of Use (78.6%) came next, followed by Learning Objectives, Student Characteristics, and Teaching Methods, each at 71.4%.

On the other hand, Accessibility (28.6%) and Cost & Availability (35.7%) were not as important. This means that teachers care more about the quality of teaching and student engagement than about the cost and availability of materials when choosing what to use in the classroom. Based on this information, using E-Comic-based teaching tools is a smart and important way to get kids interested in science. E-Comics are a digital medium that are visually appealing, spark creativity, and make learning fun and relevant. This is very similar to the top-rated aspect on the chart: attractiveness and creativity. Also, E-Comics are pretty easy to use on the digital platforms that are now widely available to both teachers and students. This supports the findings on how easy they are to use.

From a methodological standpoint, E-Comics can also be flexibly adapted to various learning objectives, student characteristics, and active learning models—all of which were perceived important by more than 70% of teachers. Thus, these findings reinforce the urgency and relevance of developing E-Comics as an innovative instructional alternative that effectively addresses teachers' needs in the field and has the potential to enhance critical thinking skills.

3.2 Development stage

There are two things to consider during the development phase: the storyline and the prompts that help people see the story. The story is based on the information in Table 1, which combines and changes the ideas. The story to choose is about an older person with dementia, whose nerves cannot send messages properly. To fit this essence, the following flowchart illustrates how the story connects scientific ideas about cells, the immune system, and the transport system.

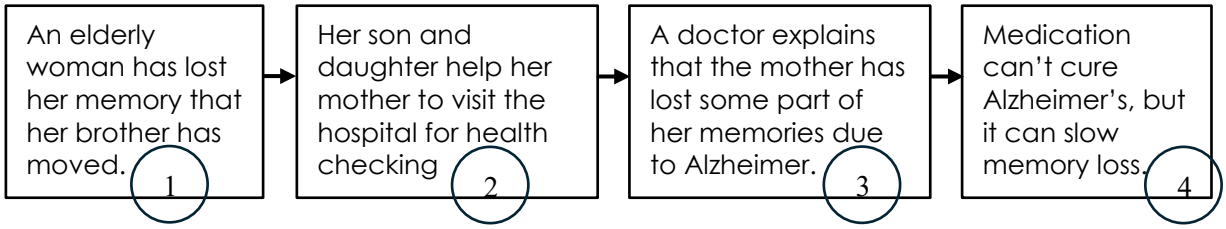


Figure 2. The flowchart of the story of e-comic

It is clear from Figure 2 that the main part of the story is in stages 3 and 4. Stages 1 and 2, on the other hand, help to explain what happens in everyday life. So, combining stages 1 through 4 will improve the e-comic's story by incorporating both social and scientific elements. Stage 3 can be enhanced in critical thinking by integrating an understanding of the mechanisms of Alzheimer's disease and its prevalence. After that, students are urged to link these two things to modern lifestyle factors. In this situation, stage 4 can show that neuronal diseases cannot be fully cured because neurons can regenerate

Table 2. The relevance of the story to critical thinking skills

Stage of the story	Indicators of critical thinking	Example in the e-comic story	Pictures
1 and 2	Making basic clarification	Asking what is happening to the mother	
2 and 3	Determining evidence for support	Asking the doctor for help	

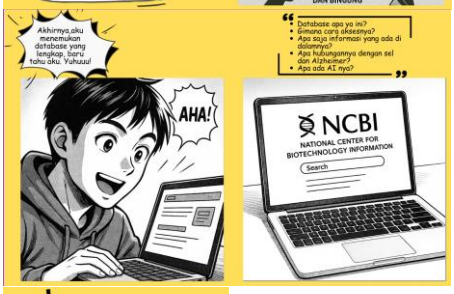
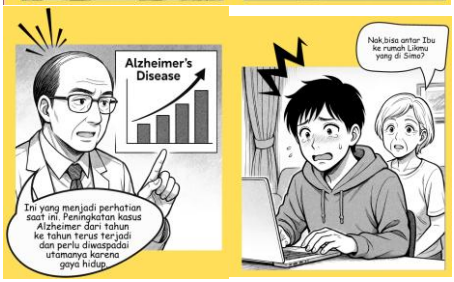
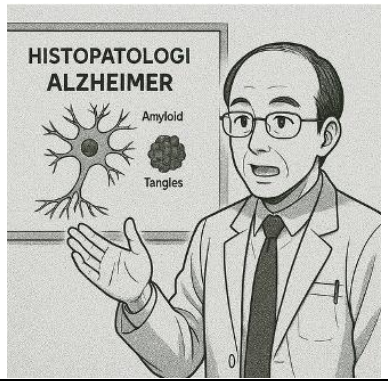
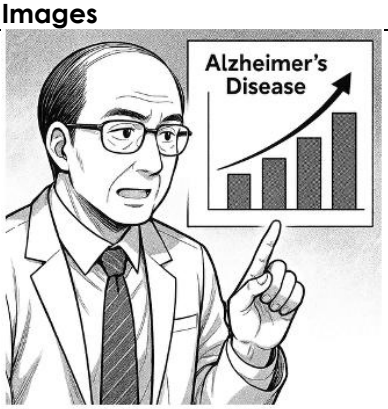
3 and 4	Doing inferential thinking	Generating information from the doctor	
	Formulating clarification in advance	Searching for information on NCBI	
4	Generating strategies	Reflecting on what has been done.	

Table 2 shows images generated by ChatGPT 4.0 that illustrate strong critical thinking skills. Since the e-comic is a way to learn, the pictures do not give all the information. Instead, they are images that make people want to read more about the subject. To demonstrate how it works to show the indicators of critical thinking skills, the conversation in each frame of the e-comic story is changed. For example, when the son thinks about "making basic clarification," he wonders, "Why does my mom forget that my uncle has moved to another city?" She also forgot the things she needed to make chicken soup yesterday. To enhance the subtleties of each frame, the background and the characters' emotions are adjusted based on the relevant prompts, as illustrated in Table 3.

Table 3: prompts to visualize appropriate images

No	Prompts	Images	Structure of prompts
1	1) A mother, 3) short white hair, short sleeves, talking, no speech bubbles, 2) appears to be talking to her son, 1) a 17-year-old boy, 3) short hair, wearing a hoodie, 4) looks surprised, 5) background is in the living room, no speech bubbles, 6)		1) Characters (first, second) 2) Behavior (first, second) 3) Physical appearances (hair, costume, etc.) 4) Expression 5) Background 6) Color 7) Style of comic

No	Prompts	Images	Structure of prompts
	black and white, 7) manga style.		
2	1) A man, 2) short hair, wearing a hoodie, 4) looks thoughtful, 3) thinking about what happened to his mother, who is starting to forget, 5) the background is in the living room, without speech bubbles, 6) black and white, 7) manga style.		1) Character 2) Physical appearance (hair, costume) 3) Behavior 4) Expression 5) Background 6) Color 7) Style of comic
3	1) A boy, 2) short hair, wearing a hoodie, 3) remembering his class lesson about Alzheimer's, in his thought balloon, the teacher is explaining in front of the class, many of his friends, without speech balloons, 4) black and white color, 5) manga style.		1) Character 2) Physical appearance (hair, costume) 3) Behavior (described in more detail) 4) Color 5) Style of comic
4	1) A man, 3) short hair, wearing a hoodie, 2) asked his sister, the sister with long hair, wearing a long-sleeved shirt, talking, talking, 4) the atmosphere was rather serious, 5) in the front yard of the house, there was a small garden, without speech bubbles, 6) black and white colors, 7) manga style.		1) Characters (first, second) 2) Behavior (first, second) 3) Physical appearances (hair, costume, etc.) 4) Expression 5) Background (more detail) 6) Color 7) Style of comic
5	1) Male doctor, 2) middle-aged, straight hair, short, slightly bald, 3) explaining, 4) histopathology, Alzheimer's, 5) black and white color, 6) manga style,		1) A character (with profession) 2) Physical appearance 3) Behavior 4) Content 5) Color 6) Style of comic

No	Prompts	Images	Structure of prompts
6	1) Male doctor, 2) middle-aged, straight hair, short, slightly bald, wearing glasses, 3) explaining, 4) Alzheimer's progression, bar chart, 5) black and white, 6) manga style		1) A character (with profession) 2) Physical appearance (wearing glasses) 3) Behavior 4) Content 5) Color 6) Style of comic

To ensure uniform images produced by prompts, it is crucial to identify the appropriate features to incorporate into the prompt formulation. Table 3 shows that creating consistent images usually requires five to seven features, such as character, behavior, physical appearance, expression, background, content (if applicable), color, and comic style. Adding more features usually makes images more detailed and complex.

Table 3 shows many features that look the same, but the information in the prompt column can vary slightly. The context of the situation, which can include characters, how they look, how they act, and their backgrounds, affects this difference. Only the color and style of the comic in manga are consistently specified to avoid inconsistencies. People think these two styles are safer than colorful and Western styles because they are already common in comic style. If you take pictures of the same thing one after the other, you might need to add more information. For example, the doctor is wearing glasses in images 5 and 6, but the content is different.

3.3 Experts' validation

To ensure the quality and suitability of e-comic media as an educational resource, a validation process was undertaken by experts who thoroughly assessed both content and media dimensions. This validation aimed to assess the extent to which the created media conformed to pedagogical standards and promoted student competency development, particularly in comprehensive learning. The results of this validation are very important for figuring out how well e-comic media works before it is used in the classroom.

Table 4. Validation results of e-comic from a content perspective

No	Items	Score
1	Comics present important core concepts/learning topics.	4
2	Stories encourage analysis, evaluation, or synthesis (Bloom's C4–C6)	4
3	Comic stories based on real problems that are relevant to students' lives.	4
4	Comics stimulate critical inquiry.	4
5	Comics encourage interaction, collaboration, or discussion.	4

The validation results in Table 4 show that the validator gave the E-Comic media a very high rating. All items were evaluated and given a score of 4. This result shows how well the e-

comic was made and how well it follows the rules of deep learning. One of the most important signs that a comic is good is that it can clearly explain basic ideas or important learning topics. These ideas are the foundation for helping students develop a deep and meaningful understanding of concepts.

Table 5. E-Comic validation from a media perspective

No	Aspects	Items	Score
1	Pedagogical	Comics clearly and specifically outline learning objectives.	4
2		Content is appropriate for the curriculum and the student's developmental level.	3
3		Comics encourage student involvement in learning.	3
4	Technical	The quality of the comic images and text is clear.	4
5		Comics are easily accessible to teachers and students.	4
6		Comics can be used in various learning devices/media.	4
7	Aesthetic	Comics have an attractive visual appearance and are age-appropriate for students.	3
8		Comics have coherent, easy-to-follow storylines.	4
9		Colors, fonts, and visual elements support understanding of the material.	4

According to the validation results in Table 5, the e-comic media created have generally met the basic requirements across three main areas: pedagogical, technical, and aesthetic. Most of the scores, which are 4, show that this is true because they show a high level of effectiveness. However, a score of 3 on a few indicators means that there is still room for improvement.

In terms of teaching, the comics were well-known for their ability to clearly and effectively communicate learning goals (score 4). Still, the other two indicators—content alignment with the curriculum and fostering student engagement—got a score of 3. This means that the media usually supports learning. However, it needs to be adjusted in more specific ways to align with students' cognitive development levels and to make the story content more interactive, encouraging active participation in the learning process.

All technical aspects were rated as perfect (score 4), including how clear the images and text were, how easy it was for both teachers and students to access, and how flexible it was to use across different devices and media. This shows that e-comic media works well from a technical standpoint and with the technology available in schools and at home.

At the same time, one aesthetic indicator still got a score of 3: the comic's attractive look and suitability for different age groups. This is an important point to consider, since the visualization, which includes character drawings, settings, and artistic style, can be further improved to better engage students. The other two aesthetic indicators—a coherent storyline and visual elements that help understand the content—are already at their best (score 4). This e-comic meets technical standards and effectively conveys general learning messages, but further development should focus on improving pedagogical aspects, especially by making

the curriculum more relevant and the story more interactive. Also, it is important to improve the visual design to make this medium even more useful and interesting for students.

The validation results show that the e-comic is attractive to readers by combining a good story with relevant images. These features will help students understand the content easily, as shown in Table 6.

Table 6. Recommendation from experts

No	Strengths and weaknesses
Strengths	
1	Comics deserve to be disseminated with easy-to-understand images.
2	The visualization technique for each panel is quite good; the images are attractive and well supported by the content.
Weaknessess	
1	The comic title should be on a separate page.
2	Some panels of the e-comic should be revised in terms of arrangement and situation. For instance, the panel containing the car image should be angled accordingly so that the reader's interpretation does not vary.
3	The box should be provided at the very end of the comic so that students can write down their understanding of the story.
4	Adding an extra panel at the story's end to enhance its essence

A framework can be created based on the results of the e-comic development stages that brings together three main parts, namely, pedagogical considerations, conceptual substance, and the use of AI through prompt engineering. The pedagogical aspect is based on the findings of a needs analysis concerning teachers' preferences for instructional media. The conceptual aspect is derived from the examination of abstract subject matter that necessitates a profound comprehension, as such content requires enhanced cognitive engagement from students. Finally, the use of AI prompts is based on five to seven main parts that help define characters, emotional situations, and environmental settings.

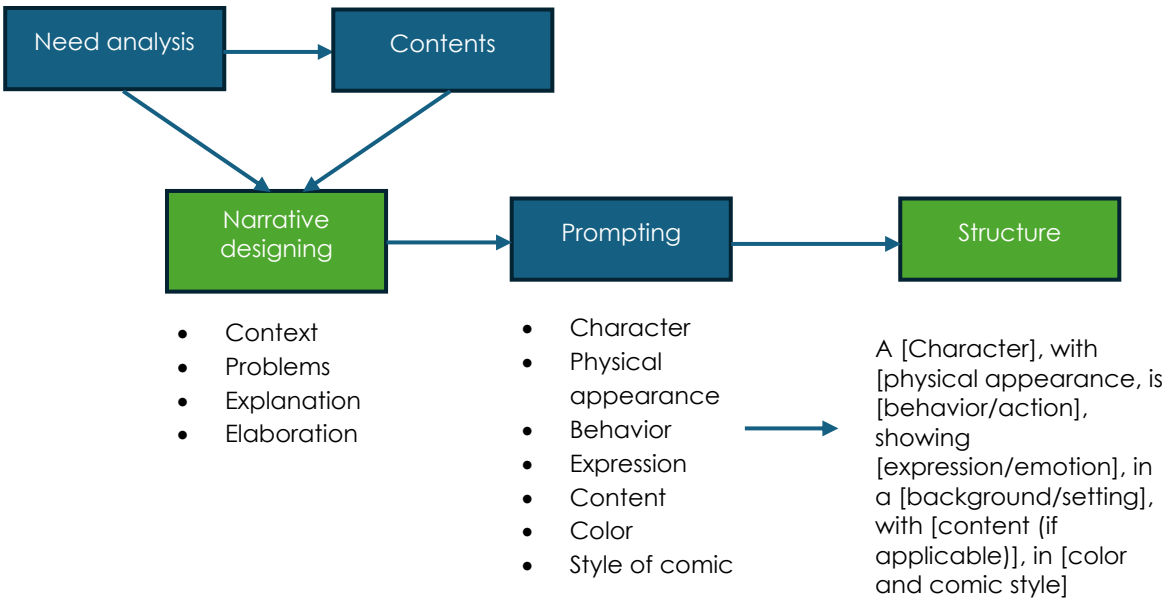


Figure 3. Framework on how to make an e-comic and the structure of AI prompting

Figure 3 above displays a series of processes for making an e-comic, from identifying needs to structuring the prompt. The narrative design should include context, problems, explanations, and elaboration to make the story rich and more closely reflect a real situation. Afterward, narrative design is translated into a prompt that includes seven items. The structure of the prompt follows the rules for writing descriptive sentences. The teachers can use the structure by changing the text within the brackets.

4. DISCUSSION

From the data obtained in this study, we can see that e-comics can be designed by combining several concepts that teachers find difficult to teach. A story about Alzheimer's can integrate concepts about cells, transport systems, and the immune system. These three concepts can be understood through damage to nerve cells (neurons), impaired microglial cell function, which clears β-amyloid, and disruption of the brain's blood transport system, specifically for removing β-amyloid. This typical story can be utilized as long as it connects more than one concept. This also enables e-comic stories to train critical thinking skills, as shown in Table 2. This aligns with the opinion that narrative dialogue and images in a series of panels require interpretation. In this case, students need analytical and synthetic skills to gain a complete understanding of the story presented (Abrori et al., 2023). Moreover, the e-comic story contains Alzheimer's disease, requiring students to understand cellular mechanisms, the increase in cases, and the effects on memory loss. The introduction of the NCBI database is also seen as beneficial in training students to see technological advances, which must also be understood through critical thinking. There is a lot of information about compounds and genes that must be combined.

Damopolii et al. (2022) and Setyowati et al. (2023) show that stories in e-comics can improve students' critical thinking skills, ranging from moderate to high. Furthermore, students familiar with science stories in e-comics show high engagement, prompting a desire to learn more. For example, the story design in Figure 2 has an easy-to-understand plot, from the social context to the underlying science. This is supported by research (Anisa et al., 2023), which states that digital comics with digestive system material can influence conceptual mastery and critical thinking skills. The findings of this study confirm that comic story design that considers social context, scientific mechanisms, and story mapping (see Table 2), as well as real-life classroom needs (Table 1), can be used to accommodate material for practicing critical thinking skills.

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A good story concept needs to be supported by engaging and consistent visualizations. As previously discussed, these two aspects pose challenges for teachers who cannot draw comics. With effective prompts in ChatGPT 4.0, relevant and consistent images can be created. The writing process can begin with describing the character, behavior, physical characteristics, expressions, background, color, and drawing style, in this case, manga. Based on the data obtained (Table 3), prompts contain at least five of these components. Effective prompts are created based on specific context and instructions. This ensures clear and unambiguous content (Ye et al., 2023). This writing context aligns with the descriptive prompting technique, which incorporates meaningful prompts that contain visual information. To produce good output with ChatGPT, Grotlüschen, Dutz, and Skowranek (2024) found a relationship between users' literacy skills and their ability to understand the cellular mechanisms underlying Alzheimer's. Often, the resulting images are misconceptions and do not resemble actual conceptual cells. Therefore, it is also necessary to have good reading skills and an understanding of scientific concepts.

Also, the results in Tables 5 and 6 employ cognitive load theory, in which the attractiveness of the e-comic potentially works to the limited working memory capacity (Sweller, 2010). Well-designed visual materials, such as structured, coherent e-comics, help reduce extraneous cognitive load by presenting information in an organized, easily interpretable manner. In addition, visually appealing content can increase students' attention and engagement, which supports the allocation of cognitive resources toward germane load. This condition allows learners to engage in deeper processing, such as analyzing, interpreting, and evaluating information, which are essential components of critical thinking. Therefore, the use of attractive and well-structured e-comics not only enhances student interest but also optimizes cognitive processing, enabling students to focus on higher-order thinking rather than being hindered by poorly designed instructional materials.

5. CONCLUSION

The research on e-comic design using ChatGPT prompts yielded a comic that can be used as a training tool for critical thinking skills, as outlined by Ennis's indicators. This outcome was achieved by exploring teachers' requirements when teaching complex subjects such as cells, the immune system, and the transport system. The e-comic can be classified as satisfactory due to the consistency of the presented images with effective

prompting that encompasses various aspects, including character, behavior, physical characteristics, expressions, background, color, and drawing style. Theoretically, it proposes an AI-Prompted Comic Design Framework that integrates pedagogy, conceptual understanding, and prompt engineering in AI-assisted learning. Practically, it offers a structured guideline for educators to design consistent and engaging e-comics using AI, particularly for teaching abstract concepts and supporting students' critical thinking. However, the primary challenge in creating this comic lies in the meticulousness of the written prompts and their interactivity. Since the results are limited to the design and creation of e-comics, further study should examine the impact of e-comics on students in a classroom setting to determine whether they are effective in enhancing critical thinking skills.

6. ACKNOWLEDGEMENTS

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