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Science Comics to Explore Thomson's Hypothesis about Negatively Charged Particle

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Abstract

This research introduces an innovative educational resource for Physics education, focusing on the captivating story of J. J. Thomson's. Comics, with their visually immersive nature, effectively merge text and visuals to accommodate diverse learning styles. They engage students through narratives and vivid visuals, enhancing the educational experience. Utilizing Thiagarajan's 4D approach (define, design, develop, disseminate), the study collects historical sources in the definition stage and meticulously plans visual narratives in the design stage. Visual literacy is highlighted, enabling students to critically analyze visual information. In the development stage, comics are refined, expert-evaluated, and tested on users. These comics are then disseminated via the Webtoon platform. The results highlight comics' potential as a valuable teaching tool, captivating students with engaging narratives and rich visuals, making Physics education more enjoyable. Moreover, comics demonstrate their broader relevance in Physics instruction, contributing to the ongoing discourse on innovative and visually engaging teaching methods.

Keywords: *Physics Comics, Negatively Charged Particles, Thomson*

INTRODUCTION

In high school physics, specifically atomic physics, discussions about charged particles are an essential part of the curriculum (Martin & Shaw, 2019). The discovery of charged particles or atoms has the significant history timeline, and J. J. Thomson plays a pivotal role in this context. In 1897, Thomson proposed hypothesis of negatively charged particles (Bhavsar & Deshmukh, 2023), which eventually became one of the most essential atomic models in physics. This model describes negatively charged particles within atoms and forms the basis for the development of modern atomic theory. J. J. Thomson conducted experiments using a vacuum tube and discovered negatively charged particles in atoms (Leo, 2020). This discovery contradicted the prevailing atomic theory, which considered atoms as indivisible and homogeneous objects. Thomson model of the atom emerged from this hypothesis, which describes atoms as positively charged balls containing negatively charged particles, such as raisins, inside (Schmiermund, 2022). The Thomson atomic model inspired the research of Rutherford and Bohr, in which they would discover a different atomic model.

In modern times, it is widely accepted that atoms consist of a nucleus orbited by electrons. The nucleus, in turn, comprises neutrons and protons, which are composed of strange particles called quarks (Barrett & Delsanto, 2020). Due to their abstract nature, comprehending the concept of atoms is often challenging for students, particularly those without a strong physics background (Cardoso et al., 2020). This means an effective method of delivering the material in class, including the history discovery of atoms, is necessary. Unfortunately, most

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textbooks only focus on the final theory without delving into the process of discovering atoms by scientists (Permana, et al., 2021). An alternative approach to presenting this information is through the use of comics as a learning medium. This approach could make the stories of hypothesis formulation and discovery more interesting.

Comics that was created to explain and tell the story about science's finding can be utilized to enhance the visual literacy of students. Through this approach, students can learn about Thomson hypothesis and the atomic concept in a fun and exciting manner. Comics can also be used to narrate stories about the life of J. J. Thomson and his struggle to discover negatively charged particles. By presenting this story in an exciting and inspiring manner, students can be motivated to learn more about physics (Baifeto et al., 2020; Luu et al., 2019). This approach aligns with the notion of making learning engaging and thrilling to increase the interest and motivation of students (Khoiriyah & Suprapto, 2021; Mahmad et al., 2015; Rachmawati et al., 2023). Comics development as a learning medium can also be carried out creatively and innovatively. There are various types of comics that can be used as media for learning physics and science including a storyline portraying time travel, where students or readers are the main characters invited to return to when the study was taking place (Siswoyo et al., 2020). Comics can contain the concise and clear explanations of material in the form of a dialogue between comics characters (Özdemir, 2017). Comics also that include stories about the history and experiments carried out by scientists directly (Permana et al., 2021; Saud, 2018; Manu et al., 2016). These three methods have their respective advantages, and since the story is presented interestingly and does not deviate from the actual incident, the creative development of comics is permissible.

As a learning medium, comics have advantages in conveying information through exciting pictures and stories. It can also visualize abstract physics concepts, which aids students in understanding these concepts (Priyadi & Kuswanto, 2023). Furthermore, comics have great potential as a tool for teaching physics. They have been used successfully to teach a variety of topics, including: Newtonian gravity (Nikmah et al., 2019), static fluids (Suri et al., 2021), black body radiation (Özdemir, 2017), microscopes (Handayani et al., 2019), sound waves (Ramadhan et al., 2019), thermodynamics (Sari et al., 2019), negatively charged particles (Permana et al., 2021), heat and temperature (Siswoyo et al., 2020; Rashid et al., 2023). One example of a successfully developed material in comics form is black body radiation (Özdemir, 2017), which is a significant topic in modern physics. Many students experience difficulties understanding modern physics concepts because of their abstract, complex, illogical, mind-boggling, and unimaginable nature. However, after being presented in comics form, the delivery becomes easier, and the stories presented are even more entertaining (Özdemir, 2017). This shows that comics offer several advantages compared to traditional learning media, such as textbooks. Apart from being more exciting and fun for students, comics can also help students understand physics concepts more easily and effectively (Permana et al., 2021).

The development of critical visual literacy skills is crucial for 21st-century students (Romero & Bobkina, 2021). This requires proficiency in skills such as summarizing and interpreting verbal messages, visual design elements, inference, and questioning, which are all essential in fostering critical thinking. Visual literacy is closely related to critical thinking because it requires a range of cognitive processes that range from simple identification to complex interpretation at contextual, metaphorical, and philosophical levels. Therefore, comics are an appropriate medium for improving visual literacy skills. The use of comics as a learning medium can help students improve reading skills and visual literacy, which are very important in the digital era today (Williams, 2019). In the 21st century, literacy goes beyond reading and writing, and it encompasses information literacy. Ferguson identified six components of information literacy, namely Early Literacy, Basic Literacy, Library Literacy, Media Literacy, Technology Literacy, and Visual Literacy. Visual literacy is the ability to understand and interpret information using images or visuals (Kellner & Share, 2019).

The use of comics can enrich the learning media used by teachers in teaching physics. Comics are popular among high school students due to their humour, narrative, and visual imagery (Spiegel et al., 2013), making them an ideal alternative medium for learning physics. They are useful as an innovative tool in the classroom because students can read comics in their spare time (Jee & Anggoro, 2012) and as a medium to help the apperception of students. Before attending face-to-face classes, students can be asked to read comics developed by J. J. Thomson and then write a summary of what they have read. This approach can attract the attention of students and make learning more interactive. In previous study (Jian, 2023), students have a positive attitude toward reading comics and are more likely to learn science through this approach than through texts. Using comics instead of textbooks is more profitable for students with moderate abilities is more profitable when learning science topics (Lin et al., 2016). Specifically, students who read comics dig up more information from science comics, leading to better post-test scores (Jian, 2023).

Along with technology development, digital comics have become increasingly popular as a medium for learning, including in the field of physics (Khoiriyah & Suprapto, 2021). To make physics learning more accessible, applications and websites that provide physics comics have been developed. This trend suggests that there is great potential for further development of comics as a medium for teaching physics. These learning comics can be accessed online through various websites, applications, and platforms. Some comics can even be downloaded and accessed offline, but often require installation on the device of the user. However, one drawback of applications developed without being uploaded to a trusted store such as Google Play store or Appstore is the licensing process for installing the applications (Suleman et al., 2021). This causes users to be lazy to install the application.

Reliable and easily accessible applications for online comics include (1) Line Webtoon, (2) Mangatoon, (3) BILIBILI Comics, (4) Comics Kingdom, (5) Manta, such as Comics & Graphic Novels, and (6) Literacy Comics KIPIN, etc. Among these, Line Webtoon has the highest number of installations, which also means it has many readers. The application can be downloaded from a trusted store or accessed through a browser, requiring readers to access the platform online. This has changed the habit of reading comics from hardcopy to softcopy. The trend of reading comics online has been developing since the early 2000s (Clark, 2012) and continues to grow. This is supported by data from "We Are Social" on world internet users, showing that the number of global internet users reached 4.95 billion in early 2022, with internet penetration reaching 62.5 % of the world population (We Are Social, 2022). Moreover, the number of internet users within the age range of school students (K12) is also increasing every year, and online comics platforms may be among the things they access. This indicates that online comics have great potential in developing science learning materials and be officially used in schools (Jam et al., 2011). Line Webtoon is currently the online comics platform with the largest number of readers, offering a wide range of genres such as drama, fantasy, kingdom, comedy, action, a slice of life, romance, thriller, horror, and local. Recently, many educational developers of comics have utilized Line Webtoon as a platform to publish their comics. Physics education comics can be easily searched using the following link https://www.webtoons.com/id by adding the keyword "physics". There are 13 comics related to physics available on the website, catering to students of all ages. The first comics of physics uploaded on Webtoon was "Komik Fisika" by Ndy Rendi, which launched its first episode in 2016. Subsequently, many physics comics have been released on the platform, and there has been an increase in the number of physics comics series by various creators over the last three years.

The further development of comics as a medium for learning physics is necessary to maximize their potential use. It is essential to conduct a study on the effects of using comics in learning physics on the ability of students ability to understand physics concepts. Additionally, further investigation is needed to develop compelling and engaging comics for students (Matuk et al., 2021). The focus of this article is on the development of comics regarding Thomson hypothesis and their relation to the use of comics as a medium for learning physics. This article aims to provide a clear picture of the potential use of comics as a learning medium in conveying stories about Thomson hypothesis and the concept of atoms interestingly and effectively.

METHOD

Thiagarajan 4D Research Model

The Thiagarajan 4D approach, also known as the 4-D Model of Instruction, is a systematic method used in instructional design to create engaging and effective learning materials. This model comprises four stages: Define, Design, Develop, and Disseminate. In this study, we applied this approach to craft comics that enhance the learning of physics in school settings.

In the definition stage, our initial goal was to develop comics centered around the life and work of J. J. Thomson, a prominent physicist known for his discovery of the electron. To align the comics with the curriculum standards, the research team carefully analyzed the requirements of the physics subject, ensuring that the content met educational objectives. Specific learning outcomes were formulated, detailing the knowledge and skills that students should acquire through reading the comics.

Moving on to the design stage, we conducted a comprehensive literature review related to J. J. Thomson's research and the historical context in which it occurred. This phase allowed us to gain a deep understanding of the subject matter and identify key events, hypotheses, and scientific discoveries associated with Thomson's work. Subsequently, we focused on designing the plot and script, determining how to visually and narratively convey the scientific concepts in a captivating and educational manner.

The development stage involved the complete realization of the comics, including the creation of illustrations, dialogues, and narratives. To ensure the quality and accuracy of the content, we engaged experts in the field of physics education. High school teachers, possessing valuable insights into the needs and preferences of the target audience, assessed the comic products. Their feedback played a crucial role in refining and enhancing the educational value of the comics. In a parallel step, we sought feedback from the ultimate users of the comics—high school students. A total of 150 students were involved in the assessment process. Their feedback and evaluations provided valuable insights into the overall effectiveness of the comics as a learning tool.

In the final stage of the process, the dissemination phase, we selected Line-Webtoon as the platform for distributing the comics. Leveraging this popular digital platform allowed us to reach a wide audience of students and educators, making the comics readily accessible for use in physics classrooms. The Thiagarajan 4D approach provided a structured and systematic framework for developing these educational comics, ensuring that they not only engage and excite students but also align with curriculum standards and facilitate effective physics learning. This methodological approach not only guided the creation of these comics but also serves as a valuable model for the development of educational materials in various disciplines.

Material Development

In this section, a detailed account of the steps and considerations that underpin the creation of comic materials, a pivotal aspect of our research, is presented. This section is utilized as a crucial bridge between the conceptualization of our educational resources and their alignment with the research objectives. This opening serves as a clear lens through which insights into the development of the comics central to our study can be gained. The subsequent step, "Selection of Historical Sources," delves into the criteria and methodologies employed in the careful selection of historical sources related to J. J. Thomson's e/m hypothesis. The paramount importance of choosing accurate and relevant historical content to ensure the educational value and authenticity of the comics is emphasized. "Content Research" then takes center stage, offering a deeper dive into the research process undertaken to comprehend and interpret the selected historical sources. This phase entails an exploration of Thomson's original papers, relevant scientific literature, and historical records to ensure the utmost fidelity to historical facts.

With our historical foundations firmly established, "Plotline Formulation" follows, elucidating the creative process behind the crafting of narratives for the comics. How the raw historical content was transformed into coherent and engaging plotlines that seamlessly align with our educational objectives is detailed. The subsequent "Script Development" elucidates how the scripts for the comics were meticulously crafted. This includes the artful construction of dialogues, captions, and explanations to effectively convey complex scientific concepts while sustaining an engaging storyline.

The focus then shifts to the "Visual Design and Illustration" aspect, wherein the planning and execution of the visual elements within the comics are outlined. The pivotal role of illustrations, graphics, and other visual components in enriching the educational content and captivating the reader is discussed. "Alignment with Educational Objectives" underscores the importance of ensuring that every element of the comics aligns seamlessly with our specific educational objectives. This phase expounds upon the deliberate choices made to reinforce the educational goals that were set out to achieve in our study.

In "Expert Review," the possibility of expert evaluation of the comic materials is addressed. If insights and feedback were provided by experts in physics education or relevant fields, their contributions and their influence on the developmental process are discussed. "Pilot Testing," if applicable, is the next step, and it is where any feedback loops involving students and educators during the material development phase are described. This is a moment to highlight any adjustments or enhancements made based on this valuable feedback. As the "Conclusion of Material Development" is approached, the entire material development process is summarized, bringing to light key decisions, challenges, and successes. The crucial link between the comics created and the educational objectives underpinning our research is underscored. Finally, as the transition to the next section is made, be it "Expert Validation" or another methodological component, a smooth flow that guides our readers seamlessly through the research journey is ensured. This meticulous presentation of our material development process aligns our comics with the broader objectives of our study, making it an integral part of our research methodology. Table 1 displays the comic panels along with the scripts that have been developed.

Table 1. Comic Panel and Script

Panel	Script
1	Featuring four scientists who are interested in the research of negatively charged particles described by Hallwachs. These figures are Philip Lenard, Jean Perrin, W. Wien, J. J. Thomson. Different experiments were conducted by these four scientists, but similarities were found. The research conducted by them was related to the discovery of unknown particles using light radiation.
2	J. J.Thomson met with Heinrich Hertz and then asked him J.J. Thomson : So what dimension does this particle actually come from? Hertz : UH? it seems like it's just subatomic
3	While Hertz and Thomson were having a dialogue, Philipp Lenard suddenly arrived J.J. Thomson : and why are you here Lenard? Lenard : But, it could be an immaterial ray of light? Hertz : NO.. it seems like it's just subatomic *Full panel and script in Appendix 1.*

Expert Validation

Media and material experts played a pivotal role in meticulously scrutinizing the comics, ensuring their content and accuracy met the highest standards of excellence. This discerning assessment extended to encompass the purview of high school physics teachers, who undertook the formidable task of evaluating the material's suitability for integration into the high school physics curriculum. The overarching objective was to ascertain the comics' alignment with the educational requirements and pedagogical rigor demanded at this level of learning.

Simultaneously, the validation process encompassed an in-depth examination of the comics as a pedagogical medium. It sought to gauge their appropriateness for student engagement within the classroom setting. To facilitate this, a comprehensive questionnaire was thoughtfully designed, leveraging a Likert scale spanning from 1 to 5. This tool enabled experts to assess various dimensions and facets of both the material and the medium with a nuanced perspective, ensuring a holistic validation process. The specifics of the material and media validation statements, along with their corresponding components, can be found in Table 2, offering a detailed of components and the number of material and media validation.

Table 2. The components and the number of material and media validation

No	Validation	Components	Statements Number	Total Statements
1	Material Experts	Material Suitability (MS)	8	22
		Presentation Technique (PT1)	7	
		Language (L1)	7	
2	Media Experts	Technology Graphics (TG)	10	26
		Presentation Technique (PT2)	8	
		Language (L2)	8	

Students Instrument

Pretest and posttest assessments will be administered to students. They will subsequently be requested to complete the research instrument utilized in this study, titled "Effects of Comics on Students' Understanding." Assessment tools commonly used in research and educational settings to measure changes in a particular variable or outcome over a specific period are the pretests and posttests. In this study, the utilization of pretests and posttests aims to assess whether an improvement in students' understanding is observed after reading the comic about Negatively Charged Particles in the J. J. Thomson series. The pretest and posttest consist of a total of 10 multiple-choice questions. Appendix 2 provides the pretest and posttest questions, with the correct answers highlighted in yellow. All questions can be answered after reading the J. J. Thomson comic, whether the answers are implicit or explicit. The questions were administered using a Google Form, and the <g> scores for the pretest and posttest will be calculated utilizing the N-Gain equation in Equation 1. The results will be interpreted using Table 3.

$$< g > = \frac{\bar{x}_{posttest} - \bar{x}_{pretest}}{x_{maximum} - \bar{x}_{pretest}}$$ Equation 1.

Table 3. Intrerpretation g Score

g score	Interpretation
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Middle
$g < 0.3$	Low

After completing the pretest-posttest, students were also directed to fill out the Effects of Comics on Students' Understanding questionnaire is provided in Appendix 3. The research instrument used in this study, titled "Effects of Comics on Students' Understanding," has been structured into six comprehensive parts, each intended for the investigation of students' experiences, opinions, and preferences concerning the integration of comics into their physics learning. This instrument is presented in the form of a questionnaire utilizing GForm, incorporating scales and descriptions.

In Part 1, demographic information is gathered, encompassing the students' names, grade/level, age, gender, and school, thereby enabling a more comprehensive understanding of the study's participant profile. Part 2 shifts the focus towards the students' prior experiences with comics in education. It ascertains whether comics have been previously read by the students, employed in school learning, and the frequency of such occurrences, thereby establishing a foundation for their exposure to this medium. Part 3 delves into the core aspects of the study, evaluating the effects of comics on understanding, motivation, and interest in physics learning. Students are encouraged to present their opinions concerning the influence of physics comics and whether a preference exists for learning with the assistance of comics. Part 4 delves into the students' learning preferences, encompassing their inclinations regarding the presentation of physics material in comic form or traditional written text and gauging the degree to which comics enhance their interest in the subject. Part 5 extends an invitation to students to provide additional comments and suggestions in connection to the application of comics in physics learning, thereby facilitating qualitative insights that complement the quantitative data collected. Finally, in Part 6, a warm acknowledgment and appreciation for the students' participation is extended, accompanied by contact information for further engagement. This comprehensive research instrument offers a well-rounded approach to the collection of data and opinions from students, thus contributing to a thorough investigation of the impact of comics on physics learning.

Teacher Interview Instrument

This teacher interview instrument encompasses a series of questions aimed at gaining insights into the teacher's experiences and practices related to incorporating comics into physics or science lessons. The interview seeks to uncover the following key aspects of their teaching approach:

1. Integration of Comics: The first question delves into how the teacher incorporates comics into their physics or science lessons. It explores the specific topics or concepts where comics prove most beneficial in their teaching.

2. Selection Criteria: The second question explores the process of selecting comics or graphic novels for lessons. It aims to understand the criteria considered by the teacher when choosing these materials.

3. Introduction to Comics: The third question focuses on how the teacher introduces comics to their students. It inquires about the guidance or instructions provided to ensure effective reading and interpretation.

4. Impact on Student Engagement: Question four seeks to ascertain whether the teacher has observed improvements in student engagement and comprehension of physics or science concepts since implementing comics in their teaching.

5. Balancing Teaching Methods: The fifth question addresses the balance between using comics and traditional teaching methods like lectures and textbooks.

6. Supplementary vs. Primary Resource: Question six examines whether comics are used as supplementary materials or serve as primary resources for teaching specific topics, with an example provided if applicable.

7. Challenges and Resistance: Question seven aims to uncover any challenges or resistance encountered from students, parents, or colleagues when using comics as a teaching tool, and how these challenges are addressed.

8. Assessment Methods: The eighth question explores whether the teacher assesses students' learning outcomes differently when using comics-based lessons and traditional teaching methods, and if so, how.

9. Favorite Comics: Question nine invites the teacher to share their favorite comics or graphic novels used in their physics or science classes and the reasons for recommending them.

10. Promoting Critical Thinking: The tenth question delves into strategies for encouraging critical thinking and discussion among students when analyzing and discussing comics' content in relation to physics or science.

11. Best Practices: The eleventh question seeks to extract tips and best practices that the teacher might recommend to others interested in integrating comics into physics or science lessons.

12. Connecting Concepts: Question twelve investigates how comics help students connect scientific concepts to real-world applications or historical contexts based on the teacher's experience.

13. Positive Impact: The final question solicits anecdotal evidence or student feedback that highlights the positive impact of using comics in the teacher's physics or science classes. Overall, this interview instrument aims to provide valuable insights into the successful integration of comics as an educational tool and the potential benefits and challenges associated with these comics.

Likert Scale

Media and material experts were involved in validating comics developed. Material validation was carried out by high school physics teachers to determine the appropriateness of the material used in comics for physics teaching at the high school level. Meanwhile, the validation of learning media was performed to assess the suitability of the developed media for use by students in class. Validation was conducted by administering a questionnaire with a Likert scale of 1-5. The components and the number of material and media validation statements are presented in Table 2.

In addition to the validation conducted by experts, the assessment of comics users or readers (high school students) was also obtained through a questionnaire. The questionnaire consisted of 14 statements with a Likert scale of 1-5. The scale used was as follows:

5 = Strongly Agree

4 = Agree

3 = Enough

2 = Disagree

1 = Strongly Disagree

The data obtained from the questionnaire were calculated, processed, and interpreted to assess the suitability of comics as a teaching medium. The question arising was whether "Thomson and His Hypothesis" - Exploring the History of Negatively Charged Particles through Physics Comics demonstrates that comics can be a fun alternative learning media. The feasibility interpretation is presented in Table 4.

Table 4. The feasibility interpretation

Criteria	Percentage
Very Good	81% - 100%
Good	61% - 80%
Enough	41% - 60%
Bad	20% - 40%

RESULT AND DISCUSSION

Comics created were disseminated using Line Webtoon via the following link, https://s.id/komik-JJThomson. These comics could be accessed using the Line Webtoon application, which could be downloaded from the Appstore or Playstore. Furthermore, they could also be accessed using a browser on a smartphone or laptop. Comics developed were in Indonesian, but the dialogs for each panel had been translated into English and displayed in Appendix 1. This approach had the main character J. J. Thomson and several supporting ones, such as Heinrich Hertz, W. Hallwach, and Philip Lenard. The main character performed further experiments to discover the liberation of particles described by Hallwach. Experiments were carried out by physicists, namely J. J. Thomson, using cathode ray tubes, and it was discovered that there was a deflection of the cathode rays if the tube was brought close to a charged plate. This finding formed the basis of hypothesis of J. J. Thomson regarding the theory that the atom was composed of negatively charged particles now known as electrons. Even this discovery led J. J. Thomson to get a Nobel prize. In the previous study (Thomas, 2006), in 1906, J. J. Thomson became the second British physicist (Rayleigh was the first) to win the Nobel Prize for his theoretical and experimental investigations on the conduction of electricity by gases (using cathode ray tubes).

Comics that were uploaded to Line Webtoon have been validated and revised according to input from experts. The results of the material and media expert questionnaire were presented in Appendices 4 and 5, while the validation was shown in Table 5. Out of the eight statements presented, three received an average rating of 3.5 in the MS section. The first two questions pertained to whether the content of comics supported readers in doing positive things, and following everyday life, respectively. The third question inquired whether the information conveyed in comics came from a trusted source. The validator rated the first statement as low because it was challenging to prove the relationship between the content of comics and positive activities by readers (students). Therefore, it is hoped that after reading comics of J. J. Thomson, the effect on the attitude of children, such as always being curious about everything and having enthusiasm for trying new things, would be evident(Jam et al., 2017). The second statement received a low rating as the book used as a reference for creating comics was not attached. In general, the high school physics teachers commented that comics, including their content, images, and material, had been conveyed effectively. The teacher recommended that comics for other physics materials need to be developed. This is supported by the validation results attached in Table 5, where the interpretation of comics being developed was rated as very good. This means that the material developed in comics is suitable for high school-level physics material.

Table 5. The validation results

No	Validation	Components	Average Score	Percentage (%)	Interpretation
1	Material Experts	MS	3.875	77.5	Good
		PT1	4.29	85.7	Very Good
		L1	4.14	82.9	Very Good
		Average Score	4.102	82.0	Very Good
2	Media Experts	TG	4.9	98	Very Good
		PT2	4.875	97.5	Very Good
		L2	4.75	95	Very Good
		Average Score	4.84	96.8	Very Good

In general, the media expert scores were categorized into both agree or strongly agree. Out of the 26 statements, only four were categorized as agreed, while the remaining 22 were rated as strongly agreeing. During the validation process, the media experts provided feedback regarding the language used in comics, suggesting that it should be more straightforward. This is because some of the dialogue in comics panels were deemed too formal. In addition, experts provided their input on the selection of font types, which was taken into account in improving comics. Based on the feedback provided, significant improvements were made to comics. Regarding the assessment results, the developed comics were declared suitable as teaching materials with very good assessment interpretations. Figures 1 and 2 show the uploaded images of comics using Line Webtoon.

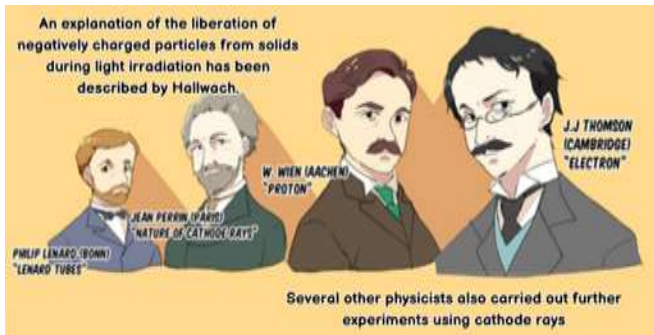

Figure 1. Panel 1 of comics contains a dialogue between several characters.

Figure 2. Contains J. J. Thomson's experiments using cathode rays that have been given positive and negatively plates.

Interviews were conducted by the researchers with elementary, middle, and high school teachers to inquire about their perceptions regarding the use of comics as a learning medium, particularly for subjects like science and physics. The interview results from science teachers at middle schools and physics teachers at high schools yielded the same conclusion as those from elementary school teachers, indicating that the conclusion that learning with comics would necessarily enhance learning outcomes could not be drawn. However, it was concurred that the positive impact of using comics in science and physics education was that it made children happier and refreshed the learning experience, preventing monotony. Regarding the content itself, suggestions were made by elementary school teachers that comics on the topic of energy could potentially be developed as teaching materials for elementary school students. In contrast, concerns about the content were not raised by middle and high school teachers.

In this interview, the elaboration of the selection of comics or graphic novels was carried out by the interviewees, highlighting the importance of choosing the right abstract topics that require visualization for effective integration into comics. The introduction of comics to students, although generally known, underlined the significance of assessing students' knowledge of reading comics effectively. Discussions regarding balancing comics with traditional teaching methods and using them as additional materials took place, with the interviewee emphasizing the role of textbooks and teacher-provided materials as the main sources for teaching. The interviewee admitted not having tried comic-based teaching methods yet, emphasizing the potential complexities in delivering concepts through comic conversations.

The discussion provided insights into potential challenges in using comics as a teaching tool, although the interviewee had not encountered such issues. Addressing the assessment of students' learning outcomes associated with comic-based lessons, the response was negative, indicating no differential assessment. The interviewee expressed a lack of experience in creating comic-based learning materials, emphasizing that, although books were interesting, no specific recommendation was given at this stage. Encouragement of critical thinking and discussion among students when analyzing comic content related to physics or science was discussed, with an emphasis on asking questions to gauge students' comprehension.

In the context of connecting scientific concepts to real-world applications or historical context, discussions revolved around comics' delivery through characters, plot, and visuals, underlining how this could facilitate students' understanding of abstract materials. However, no anecdotal evidence or feedback was provided regarding the impact of using comics in physics or science lessons. This discussion sheds light on the potential benefits and challenges of integrating comics into science education and provides insight into the interviewee's perspective. Further research is needed to evaluate the practical implications and outcomes of using comics as a teaching tool in the context of physics and science education.

During the dissemination process, readers were asked to provide feedback on comics, and the distribution of user ratings. The user questionnaire was completed by 216 high school students aged 16-18 years, and their age distribution was shown in Figure 3. The age distribution of the students is shown in Figure 3. The number of students aged 16 years is 88 students, aged 17 years is 118 students, and aged 18 years is 10 students. In the percentage figure, the age of 16 years is depicted in blue with a value of 41%, the age of 17 years is represented in orange with a percentage of 54%, and the age of 18 years is indicated in gray with a value of 5%.

The obtained average rating was 4.00, which falls under the excellent category. However, out of the 14 statements, five had an average rating below 4. The low-rated statements include the following. The attractiveness of the cover design (thumbnail) used in comics, with a value of 3.77. The ease of reading based on the size of the letters used, with a score of 3.82. The ease of reading due to the panel layout utilized, with a score of 3.82. The level of interest in the storyline, which motivates readers to study physics, with a score of 3.41. The level of anticipation for the next episode in the photoelectric effect comics series, with a rating of 3.77.

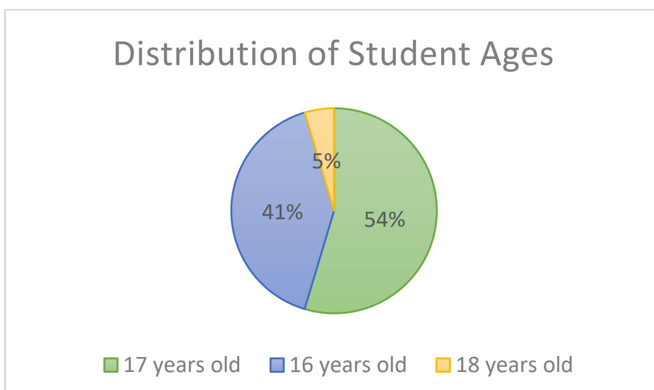

Figure 3. The age distribution of the students.

In addition, the statement that received the highest rating was regarding the material presented in order to increase the knowledge about electrons, and it has a score of 4.36. This statement received a high score because teachers rarely explained the history of the discovery of electrons in class. The experts also received positive feedback from the readers regarding their work. For example, they appreciated the insightful and exciting content, the captivating chapters, and the comparable quality to other Line Webtoon comics. These positive comments were similar to those received by other experts who developed physics lesson comics (Permana et al., 2021; Siswoyo et al., 2020; Özdemir, 2017). Based on these comments, it can be concluded that comics could be used as fun teaching materials for new students.

After the pretest and posttest were administered, the conclusion was drawn that cognitive learning outcomes were effectively improved by the use of comics from before to after the instruction. In general, the pretest recorded an average score of 61.1, while the posttest yielded an average score of 81.2, and the N-Gain Score, derived from the averages of the pretest and posttest, was 0.52. The level of improvement falls within the moderate category. An interesting discovery from this research is that, among 216 students, 7 exhibited negative N-Gain scores, indicating a decline in their posttest results. This can be attributed to various factors, and further research is warranted to ascertain the causes. The complete N-Gain data is provided in Appendix 6.

Following the administration of the pretest and posttest, the Research Instrument: Effects of Comics on Students' Understanding was also distributed. The results indicate that comics are not widely employed in high schools, particularly in the field of Physics education. More than 80% of students reported that this was the first physics comic they had ever read, and this comic encompasses physics content. The comics they typically read were solely for entertainment purposes, devoid of any educational content. Consequently, this comic represented a refreshing departure for them. Students also expressed appreciation for how the dialogue elucidated the use of the CTR.

A 17-year-old boy reader had provided suggestions for improving the J. J. Thomson comics. The reader suggested that comics panels could be arranged closer together to improve reading efficiency without requiring much screen movement. Additionally, the reader suggested improving the image resolution quality to make the displayed illustrations easier. However, media experts, including a 30-year-old woman who conducted the media validation, did not consider these issues a concern, as they had already rated both the panel and image resolution highly. The difference in opinion was likely due to differences in the ability to form judgments about comics and their form (La Cour, 2022). Studies have shown that even within the same age range, men and women and men had different judgments and views about comics (Havard, 2020). However, other studies have found no gender differences in attitudes toward comics (Crăciun, 2019). The divergent results of these studies are probably due to differences in the types of comics being compared. For example, gender did not affect judgments about comics related to Science Education, but it did affect judgments about Marvel, DC, and Sports comics.

CONCLUSION

Physics teachers and students require teaching materials that go beyond explaining formulas related to hypothesis of J. J. Thomson. The story behind this hypothesis is also equally fascinating and engaging. While this aspect is usually not covered during regular class hours, comics designed as physics teaching aids can enhance learning and make it more enjoyable. The J.J. Thomson comics created for this purpose have been distributed using the Line Webtoon platform https://s.id/komik-JJThomson. The results indicate that Thomson comics can serve as a fun and effective learning medium. However, this approach still has limitations, such as the failure to examine the effect of gender on the evaluation of comics. In the future, there is a need to consider all the suggestions provided by readers and conduct a more comprehensive study on comics.

DECLARATIONS

Confict of Interest The authors declare that they have no confict of interest.

Ethical Statement All responses were collected anonymously. All respondents agreed to this anonymous data recording. Respondents under the age of 16 have the consent of the guardian when filling out the questionnaire.

Data Availability The appendix and dataset analyzed during the study is available in this paper.

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