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Acrachemmics (Acid Rain in Chemical Comics) Oriented to Chemical Literacy

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Abstract

Understanding chemical concepts such as acid rain can be challenging for students due to their abstract and complex nature. To address this, a chemical literacy-based learning approach using comic media. Acrachemmics (Acid Rain in Chemical Comics) was developed to enhance student comprehension. This research aims to develop and evaluate electronic comic media especially Acrachemmics (Acid Rain in Chemical Comics). A Design-Based Research (DBR) methodology was employed, comprising three phases: analysis, design, and development. The validation test yielded a Pearson correlation coefficient (*r*) of 0.88, indicating a high level of content validity. Additionally, the feasibility assessment, which examined aspects of material content, visual communication, software engineering, and language, produced an average score of 84%, reflecting a high level of practical usability. These results suggest that Acrachemmics is both a valid and feasible educational media for teaching acid rain concepts. By presenting scientific content through engaging visuals and narrative storytelling, Acrachemmics facilitates student understanding in a more accessible and enjoyable format.

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INTRODUCTION

Acid rain is a significant environmental issue that frequently occurs in everyday life and has far-reaching impacts. Studying acid rain is important in chemistry and science education to understand the impact of human activities, chemical reactions, and ecological effects, as well as to develop critical thinking skills and interdisciplinary applications (Budiwati, 2019). Acid rain is often an environmental problem that arises from human activities, especially the release of sulfur dioxide (SO_x) and nitrogen oxides (NO_x) into the air (Situmorang, 2016). This phenomenon has far-reaching impacts on ecosystems, infrastructure, and human health (Alfiandy et al., 2021). Acid rain is one example of a natural phenomenon that can be explained through an understanding of chemistry (Septiani et al., 2022). Connecting a phenomenon with learning materials can help improve student understanding (Jafar, 2021). Research conducted by Khaeriyah et al., (2022) states that acid rain is material that is considered complicated, so that learning media such as an interactive Worksheet is needed because the learning method used is still the lecture method (Irwansyah et al., 2019). Chemistry material is learning that involves mastering concepts,

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principles, and skills related to acid rain material and requires learning media. The learning media for acid rain that have been used so far are only PowerPoint, using the lecture method. The media has not been effective in helping students understand the material because it is less interesting and not contextualized (Hilala et al., 2023 Wulandari et al., 2019). Chemistry materials must use learning media because many concepts in chemistry are abstract or cannot be seen directly (such as atoms, molecules, chemical reactions) (Sari et al., 2019). Learning media (such as animations, 3D models, chemical reaction videos) help explain these things visually (Marlinasari et al., 2018; Irwansyah et al., 2019). There are many obstacles when not using learning media (Permana, 2021). Without media, abstract concepts can only be explained verbally or through writing, which often confuses students. In addition, the lack of school laboratory facilities or complete chemical tools and materials prevents conducting practical experiments directly (Situmorang, 2016).

Learning media can make content easier to understand and increase learning motivation by using interesting media (Subarkah et al., 2018; Irwansyah et al., 2017; Nugrahaeni et al., 2017). According to Dessiane & Hardjono, (2020) research, the use of electronic comics or e-comics as a substitute for traditional books can help students absorb learning information better. E-comic is a story composed of pieces of images accompanied by text and accessed through an online platform (Dessiane & Hardjono, 2020). E-comic is one of the supporting media in the learning process that combines technology with interesting story illustrations as an innovation in learning (Hanifa et al., 2023). Most students felt enthusiastic when reading e-comics (Ariyanti et al., 2024). The enthusiasm of these students shows that e-comics can increase learning motivation, understanding, and the learning process (Sholiha et al., 2017). One of the main difficulties faced by students in understanding the concept of acid rain is their struggle to connect abstract chemical concepts, such as the formation of acids from nitrogen and sulfur oxides in the atmosphere, with real-world impacts on the environment (Alfiandy et al., 2021). This lack of understanding indicates that these students' chemistry literacy is still low, particularly in aspects of scientific content, context, and processes. Many students do not realize that the chemical reactions occurring in the air can have direct effects on their lives, such as damage to plants, water pollution, and the deterioration of buildings (Sari et al., 2019 Amaliyah et al., 2018). This ignorance suggests that students are not yet able to use their chemical knowledge to explain everyday phenomena scientifically. To address these barriers, learning media such as comics are highly needed. Comics can present scientific information visually, engagingly, and contextually, thus helping students understand abstract concepts more concretely (Syahkumala, 2021). Through engaging narratives and illustrations, comics can simplify complex chemical processes into stories that are easy to understand and relevant to students' lives (Hanifa et al., 2023).

Research on e-comics has been conducted by Danu (2020) which shows the effect of using comics on creativity and the cognitive, emotional, and psychomotor learning outcomes of students. Previous research has also examined the effectiveness of using comic media in learning chemistry based on environmental literacy (Agussalim et al., 2021). The results showed that comic media can improve students' concept understanding and communication skills (Naila et al., 2022). Although there have been many studies that prove the effectiveness of comic media in learning chemistry, most of the focus is still limited to aspects of improving concept understanding or learning motivation (Nasrulloh et al., 2020). Not many studies have specifically developed comic media oriented towards chemical literacy. Based on previous research, there has been no comic learning that discusses acid rain. Chemical literacy is very important because it helps understand chemical concepts and their applications in everyday life, as well as improving critical thinking and problem-solving skills. The novelty of this research is the creation of e-comics containing acid rain material, the process of acid rain, the impact, and how to deal with acid rain, packaged in fantasy stories and colorful comic presentation design. In addition, the e-comic created is also oriented to the indicators of chemical literacy aspects, namely chemical content, chemical context, chemical processes, and chemical attitudes. The purpose of this research is to describe the design, analyze the results of the validation test and feasibility test, and describe the appearance after the validation test and feasibility test on chemical literacy-oriented Acrachemmics (Acid Rain in Chemical Comics).

METHOD

The research methodology known as Design-Based Research (DBR) creates and generates a product that aids in the learning process (Mukarromah, 2022). The Design-Based Research (DBR) method aims to design and develop a product in the learning process, such as learning media that is useful for assisting the continuity of the learning process (Allen, 2017). This method refers to the ADDIE model, which consists of five steps, namely analysis, design, development, implementation, and evaluation (Asmayanti et al., 2020; Azizah et al., 2024). However, the research conducted only reached the development stage, because it was adjusted to the research objectives, namely to produce a learning media in the form of e-comic on acid rain material, and because the e-comic made had not been fully implemented in the learning process so that the evaluation results could not be determined (Wahyudin et al., 2022). At the analysis stage, a literature review is carried out through the process of analyzing problems with the learning system in acid rain subjects, analyzing relevant articles, determining the right indicators on acid rain material, analyzing aspects of chemical literacy, and reviewing relevant sources regarding the material and media used. In the design stage, flowcharts and storyboards are made as an initial design of the e-comic application to be developed by making storylines, character designs, and layouts. The purpose of making a flowchart is to see the flow of the e-comic from start to finish. Furthermore, the process of making storyboards is carried out to see an initial picture related to the appearance and description of the flowchart. In the development stage, adjustments were made to the comic design, consisting of flow charts and storyboards for an overview of making chemical literacy-oriented Acrachemmics using the iSpring Suite 11 application. However, the research conducted only reached the development stage, because it was adjusted to the research objectives. The research procedure is as follows in Figure 1.

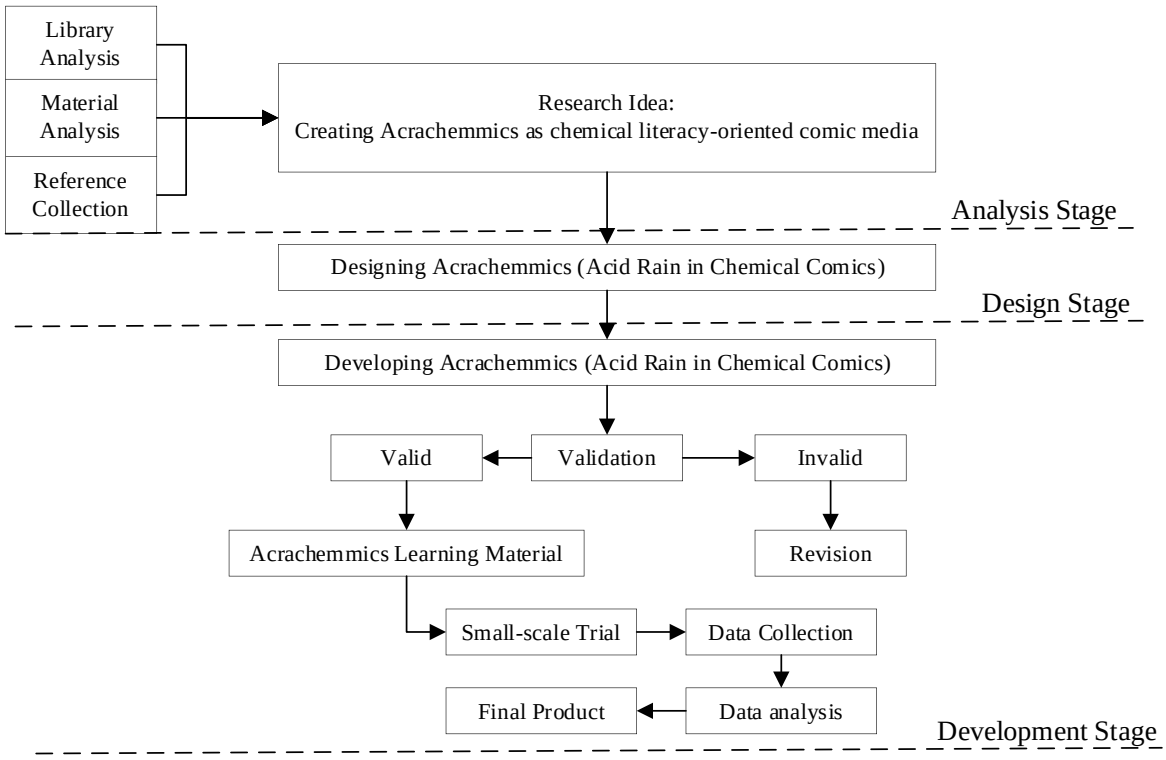


Figure 1. Development Research Produce

The validation test was carried out by three validators, namely two material experts and one media expert. The assessment criteria used in the validation questionnaire include the suitability of the material and the appearance of the media section (Wahyudin et al., 2022). After that, the data from the validation questionnaire is then analyzed to obtain a conclusion on the feasibility of the media product. Validity test data analysis was carried out by comparing the feasibility value (r) of the instrument with the critical value is said to be valid if it exceeds the critical value of 0.30. The

feasibility value (r) is the average result of an assessment that shows how feasible a product is to use. Feasibility value (r) is a study that will be used to determine whether the development of a system project should be continued or discontinued.
The formula used is:

$$r = \frac{X}{N.n}$$

With information:
r= Feasibility test score
x = Total score
N = maximum score
n = number of respondents

Then, calculate the feasibility test. This feasibility test questionnaire was filled out by prospective chemistry teacher respondents, namely chemistry education students in semester 6, a many of 15 people. The scale of the feasibility test questionnaire is Very Good (5), Good (4), Adequate (3), Less (2), and Very Less (1). To interpret the feasibility test results, the Pearson correlation coefficient (r) was categorized into levels as shown in Table 1, which helps to determine the degree of feasibility based on the obtained score.

Table 1. Interpretation Categories for Pearson Correlation Coefficient (r)

r Value Range	Interpretation Category
0.81 ≥ r ≤ 1.00	High
0.61 ≥ r ≤ 0.80	Moderately High
0.41 ≥ r ≤ 0.60	Somewhat Low
0.21 ≥ r ≤ 0.40	Low
0.00 ≥ r ≤ 0.20	Very Low

The validation test is conducted by experts because it requires professional expertise and knowledge to assess the theoretical and technical quality of a product. The feasibility test is conducted by students (or other users) because they will use the product directly, so they can provide input on the practicality and benefits of the product (Irwansyah et al., 2019).
Data processing in the feasibility test can use the following formula:

$$\% \text{ Result} = \frac{Total\ score\ obtained}{Maximum\ score} \text{ x } 100\%$$

Then, after getting the percentage value of the feasibility of the data, it can be categorized into levels of feasibility. These categories serve as a reference to determine how appropriate the developed media is for implementation, as shown in Table 2.

Table 2. Feasibility Category Based on Percentage Score

Percentage Range	Category
90-100 %	Very Feasible
80 – 89 %	Feasible
70-79 %	Decent enough
60-69 %	Less feasible
<60	Very unfeasible

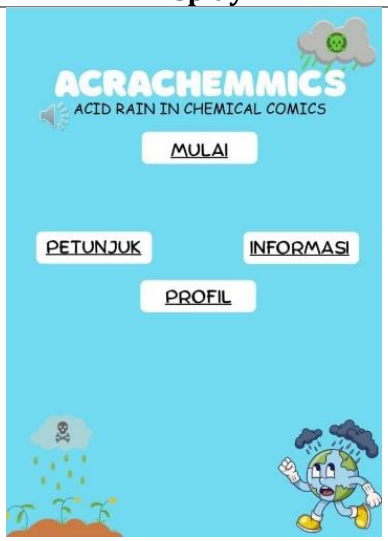
RESULTS AND DISCUSSION

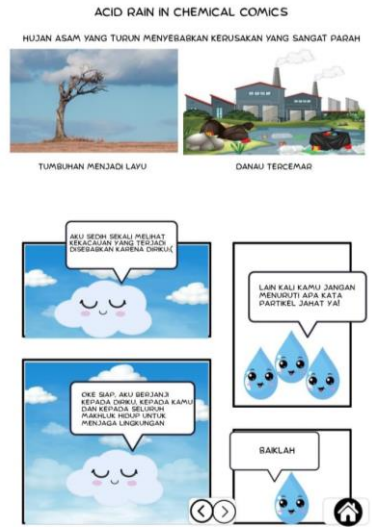
The results of this study were obtained from filling out a validation test questionnaire from three validators and a feasibility test questionnaire from 15 chemistry education students.

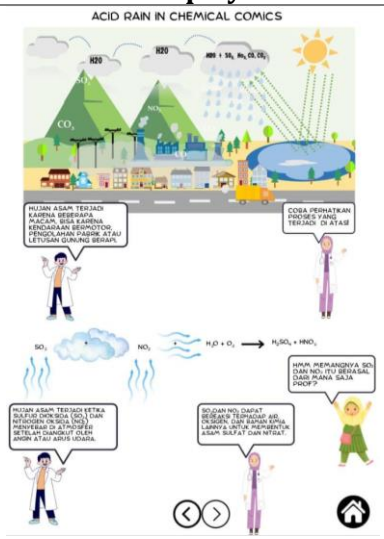
The Description of the Application Display

Taking into account the display's aesthetics is one of the most crucial elements of planning and producing comic-based educational materials (Naila et al., 2022). Research conducted by Naila et al., (2022) states that the aesthetic aspect is evaluated through validation of visual appearance, which shows that attractive visual design is considered important in improving students' concept understanding and communication skills. To make the game easier to play, for instance, the pictures should be appropriate for the content, take into account the arrangement or positioning of the text and images, and make sure the directions are clear (Maghfirah & Herowati, 2018). Acrachemmics (Acid Rain in Chemical Comics) is a comic media of acid rain material that is designed to make learning easier, make students understand the concept of acid rain more, and increase students' enthusiasm increase in learning. This comic is designed with Chemical literacy in mind. Chemical literacy skills are important because they can improve the way a person thinks (Buchori & Setyawati, 2015). The creation of this e-comic contains acid rain material, the process of acid rain, the impact, and how to deal with acid rain, which is packaged in fantasy stories and colorful comic presentation designs. Here is a look at Acrachemmics (Acid Rain in Chemical Comics) oriented to Chemical Literacy can be seen in Table 3.

Table 3. Display and Description of the Acrachemmics

No	Display	Description
1		This section is an early look at the opening of Acrachemmics (Acid Rain in Chemical Comics). The "Start" button shows the button to go to the comic story frame. The "Hints" button is to go to the frame of the comic usage instructions. The “information” button is the button to go to the information frame. And the "profile" button is the button to go to the frame, the compiler's profile.
2		This section informs instructions for use along with an explanation of each icon in it.

No	Display	Description
3		In the information section, it contains an explanation of the learning outcomes and learning objectives of Acrachemmics (Acid Rain in Chemical Comics).
4		In one part of the comic storyline, here shows one of the aspects of chemical literacy, namely chemical content. This chemical content refers to acid-base matter. Acid rain can be detected with litmus paper as an indicator.
5		The comic storyline section features one of the parts of chemical literacy, namely the chemical context. This display shows the context of the acid rain phenomenon and the impact that occurs due to acid rain.

No	Display	Description
6		The comic storyline section features one of the parts of chemical literacy, namely the chemical process. This display shows the process and reaction of acid rain.
7		The comic storyline section features one of the parts of chemical literacy, namely chemical attitudes. This display shows the attitude we should take to prevent acid rain from occurring.
8		In the quiz display, Acrachemmics (Acid Rain in Chemical Comics) consisted of several multiple-choice questions as evaluation material for the comics presented.

No	Display	Description
9		In the second Acrachemmics (Acid Rain in Chemical Comics) quiz display, it consisted of several true or false questions as evaluation material for the comics presented.

Acrachemmics (Acid Rain in Chemical Comics) is a digital comic for acid rain material designed to simplify the learning process, increasing students' enthusiasm and interest in reading. The advantage of Acrachemmics (Acid Rain in Chemical Comics) is its interactive display, which is easily accessible through various devices such as smartphones, tablets, and computers. This comic is equipped with zoom features, light animations, and narration audio to enrich the reading experience. In addition, the expressive character design and simple language style make complex science material easier to understand and engaging. With a powerful combination of visuals and digital technology, this comic effectively increases reading interest while deepening understanding of environmental issues such as acid rain.

Result of the Validation Test

The validation test was carried out with the aim of determining the accuracy of the content in the research instrument. The validation test is carried out by giving a questionnaire to the validator. The validator who conducts the validation test is a lecturer who is competent in his field. The validation test is carried out by validator lecturers, namely material experts, media experts, and learning experts. The validation test was conducted offline from April 16, 2025, to April 23, 2025. The overall results of the validation test can be seen in the table.

In this table are the results of the material validation test. Based on the material validation data obtained from the results of the validation test by three validators, it was obtained that the average score of the calculation for the validity of the learning aspect of the material was 0.91, the substance of the material was 0.90, the quiz was 0.95, the language was 0.87, and the literacy was 0.89. The average value of the calculation for each validity test is above the critical value (0.3). Therefore, the materials and media packaged in the e-comic on acid rain materials oriented to chemical literacy are declared valid. The overall average result can be seen in Table 4.

Table 4. Validation Test Result

No	Statement	$R_{calculate}$	R_{crit}	Result	Interpretation
1	Material learning aspects	0,91	0,3	Valid	High
2	Aspects of material substance	0,90	0,3	Valid	High
3	Quiz	0,95	0,3	Valid	High
4	Linguistics	0,87	0,3	Valid	High
5	Literacy aspect	0,89	0,3	Valid	High
	Average	0,90	0,3	Valid	High

Table 4 shows the results of the e-comic display validation test. Based on display validation data obtained from the results of the validation test by three validators, it was obtained that the average value of the calculation for the validity of the e-comic display was 0.85, Linguistics 0.88,

Visitability 0.86, Graphic elements 0.9, Software engineering aspects 0.84. The average value of the calculation for each validity test is above the critical value (0.3). Therefore, the materials and media packaged in the e-comic on acid rain materials oriented to chemical literacy are declared valid. The overall average result can be seen in Table 5.

Table 5. Validation Test Result

No	Statement	$R_{calculate}$	R_{Crit}	Result	Interpretation
1	E-comic display	0,85	0,3	Valid	High
2	Linguistics	0,88	0,3	Valid	High
3	Visitability	0,86	0,3	Valid	High
4	Graphic elements	0,9	0,3	Valid	High
5	Aspect of software engineering	0,84	0,3	Valid	High
	Average	0,86	0,3	Valid	High

Based on the validation results of 3 validators that contained the e-comic material and display section, it was concluded that the average results of the e-comic material and display validation test obtained an average score of 0.88 and hereby Acrachemmics (Acid Rain in Chemical Comics) Oriented Chemical Literacy was declared valid accompanied by feedback and recommendations from the validators to make improvements.

Result of the Feasibility Test

Next is the feasibility test. This feasibility test was carried out using a checklist questionnaire as a measuring tool for Acrachemmics (Acid Rain in Chemical Comics), which has been completed. This feasibility test produced data obtained from the responses of 6th-semester students on April 24, 2025. The results of the feasibility test can be seen in Table 6.

Table 6. Feasibility Test Result

No	Statement	Presentation	Remark
1	Visual communication aspects	79	Feasible Enough
2	Aspects of software engineering	93	Very Feasible
3	Aspects of material substance	84	Feasible
4	Linguistic aspects	80	Feasible
	Average	84	Feasible

There are four aspects contained in the feasibility test questionnaire, as mentioned in Table 6, namely the visual communication aspect, the software engineering aspect, the material substance aspect, and the language aspect. The visual communication aspect is aimed at analyzing the design, proportions of text size, audio, and flow contained in Acrachemmics. The results of the feasibility test for the visual communication aspect obtained 79% with a fairly decent category, and this proves that Acrachemmics has an attractive visual design. The software engineering aspect is aimed at analyzing the suitability of the instructions for use, program control, ease of e-comic installation, and interconnection in the quizzes contained in Acrachemmics. The results of the software engineering feasibility test obtained 93% in the very feasible category, and this proves that Acrachemmics has high ease of access and proportional suitability.

The substance aspect of the material is aimed at analyzing the suitability of the concept presentation, the clarity of the concept, and the skills in the presentation of the concept of acid rain contained in Acrachemmics. The results of the feasibility test for the substance of the material obtained 84% in the feasible category, and this proves that Acrachemmics has good quality in presenting the concept. The linguistic aspect is shown to analyze the suitability of graphic design, selection of tools, accuracy of layout, clarity of plot, selection of characters, suitability of images with stories, accuracy of conversation balloons, and font suitability contained in Acrachemmics. The results of the feasibility test on the linguistic aspect obtained a score of 80% in the feasible category, and this proves that Acrachemmics has good quality and graphic design aesthetics.

The quiz aspect is higher than language because quizzes are designed to measure understanding and application of concepts directly. Quizzes usually have a more structured and

objective format, which makes scoring easier. On the other hand, language aspects in student feasibility tests can be more subjective and subject to interpretation, which can lead to variations in scoring. The quality of the language used in the feasibility test, while important, does not necessarily reflect the students' overall ability to understand the material. In addition, no notes or problems were found by the validators during the validation test process. This indicates that the assessment process went smoothly and the results were as expected. With no problems, this can strengthen confidence in the effectiveness of the assessment method used. Comics as an educational media have great potential to transform the way students understand complex concepts (Fitri et al., 2022), such as acid rain. Future developers need to focus on narrative strategies that explain chemical and environmental processes in depth while remaining engaging. Innovative visual designs and narratives that engage students' emotions will be key to the success of this learning media. Furthermore, acid rain comics should be able to integrate aspects of science, environmental awareness, and socio-economic impacts comprehensively. Developers need to design content that not only explains chemical phenomena but also invites students to think critically about environmental impacts and the role of humans in preventing ecosystem damage.

On the software engineering aspect, I used a platform that supports ease of navigation, is responsive on various devices, and is technically stable, so that the user experience is comfortable and interactive. For the material substance aspect, I compiled the comic content based on the applicable curriculum and validated it by material experts to be scientifically appropriate and accurate. As for the linguistic aspect, I used communicative language, easily understood by students, and adapted to their level of language development, without omitting important chemical terms. The combination of these four aspects is designed in a balanced way so that the comic is not only interesting but also functional and educational. Based on the results of the feasibility test, the average was calculated, and the percentage result was 84% and included in the feasible category. These results show that the chemical literacy-oriented Acrachemmics (Acid Rain in Chemical Comics) product can be used as a learning media for acid rain materials.

Research conducted by Hanifa et al. (2023) shows that comic learning media are suitable for use as teaching materials in biology so as to increase student interest. The same research was also conducted by Yuselita et al. (2019), which was proven by the results of comic media for chemical bonding material that is suitable for use. In addition, 96.3% of students gave a positive response to comic media and were included in the very good response category. The results of research conducted by Dessiane & Hardjono (2020) show that comic learning media at the Elementary School level is considered suitable for use as teaching materials. The results of the analysis show that the use of comic media or illustrated stories in elementary school students can increase students' positive responses in learning. Based on previous research, all of them have progressed when using comic media. The research that I developed has similar results to previous research.

The results of previous research on the use of comics as learning media show that comics can increase interest in learning, strengthen concept understanding, and help students remember material visually and narratively. The implications of these findings for education are significant, especially in encouraging learning innovations that are more fun and meaningful, especially for students with visual learning styles. Comics also have the potential to reduce boredom in the learning process and help teachers deliver complex material more simply and interestingly. However, the study has limitations, such as the limited sample that only covers certain levels of education, the lack of variety of topics in the comics used, and the long-term impact of using this media has not been evaluated. In addition, this study only involved 6th-semester students, so the results may not be generalized to other levels or regions. The trial of comic media was carried out in a limited time, so it has not been able to evaluate the long-term impact on improving student understanding. Therefore, more extensive and in-depth follow-up research is needed to test the effectiveness of comics in various educational contexts and on various characteristics of learners.

LIMITATIONS

While this research successfully highlights the development and feasibility of the Acrachemmics (Acid Rain in Chemical Comics), it does not extend to evaluating its long-term effectiveness or adaptability in varied educational settings. Future investigations are encouraged to bridge this gap by assessing its broader impact on student learning outcomes.

CONCLUSION

In this research, Acrachemmics (Acid Rain in Chemical Comics) has been successfully developed, which is oriented towards chemical literacy with an attractive appearance and is equipped with a clear storyline. In this comic, there is also a quiz feature that can evaluate learning outcomes directly. The validation test results show an r_{count} value of 0.88, indicating a high level of validity. Furthermore, the results of the feasibility test resulted in a percentage of 84%, indicating that Acrachemmics as a learning media has proven to be feasible to use. This comic contributes to increasing students' interest in learning through an interesting visual and narrative approach. This product can be an alternative learning media that is innovative and fun, especially for theoretical material. Comics should be further developed for other materials and tested over a longer period. Therefore, the researcher suggests further research to improve the comic.

AUTHOR CONTRIBUTIONS

RK contributed to conceptualization, data collection, and manuscript drafting. FSI and CDD provided supervision, content validation, and critical review of the manuscript. ID contributed to the instructional design and refinement of the chemical literacy framework. YAG was responsible for the development and evaluation of the digital comic media. All authors read and approved the final version of the manuscript.

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