JPII 14 (1) (2025) 59-69

Jurnal Pendidikan IPA Indonesia

https://journal.unnes.ac.id/journals/jpii

INTEGRATION OF ANALYTICAL CHEMISTRY FLIPBOOKS BASED ON PROJECT-BASED LEARNING IN IMPROVING CRITICAL THINKING SKILLS AND SCIENTIFIC LITERACY TO SUPPORT SDG-4

S. A. Sari*[1], R. S. Dewi[2], K. Saputra[3], A. Kembaren[4], H. Hasibuan[5], C. A. Talib[6]

[1,2,4,5] Department of Chemistry, Universitas Negeri Medan, Indonesia
[3]Department of Computer Science, Universitas Negeri Medan, Indonesia
[6]Department of Chemistry Education, Universiti Teknologi Malaysia, Malaysia

DOI: 10.15294/jpii.v14i1.21038

Accepted: February 15th, 2025. Approved: March 29th, 2025. Published: March 30th 2025

ABSTRACT

This study was aimed at assessing the effectiveness of Project-Based Learning (PjBL)-based analytical chemistry flipbooks in improving students' critical thinking skills and scientific literacy, and linking the results to the achievement of Sustainable Development Goals (SDG-4), namely quality education. This study used a quantitative approach with a quasi-experimental design, involving two groups: an experimental group (n = 250) using PjBL-based flipbooks, and a control group (n = 250) using conventional textbooks. The projects in PjBL were designed to challenge students to apply critical thinking skills in solving real problems in analytical chemistry. Scientific literacy was measured based on students' ability to understand, evaluate, and apply chemical concepts in the context of the project. Critical thinking skills and scientific literacy tests were used to measure learning outcomes before and after the intervention. The instrument in this study was a test of critical thinking skills and scientific literacy. Statistical tests showed that the data were normally distributed (significance value 0.216), homogeneous variance (0.074), and significant differences between the experimental and control groups ($t = 0.038$, $p < 0.05$). The increase in n-gain in the experimental group reached 0.9 (high category), compared to 0.63 (moderate category) in the control group. This study concluded that Project-Based Learning-based flipbooks were significantly more effective than conventional textbooks in improving students' critical thinking skills and scientific literacy. The results of this study confirmed the superiority of PjBL-based flipbooks in significantly improving students' critical thinking skills and scientific literacy compared to conventional textbooks. Statistical data support (normal distribution, homogeneous variance, significant differences between groups, and high n-gain in the experimental group) encourages the adoption of PjBL-based flipbooks as an effective learning strategy to achieve quality education according to SDG-4.

Keywords: critical thinking; scientific literacy; flipbook; project-based learning; analytical chemistry

INTRODUCTION

Critical thinking skills and scientific literacy are essential for students to face the challenges of the 21st century. The Program for International Student Assessment (PISA) 2022 shows that Indonesia faces major challenges in scientific literacy. Indonesia is ranked 68th and has an average score of 398 in science, 379 in mathematics, and 371 in reading (Endaryati et al., 2021). These results highlight the need for further efforts to improve the quality of education, especially in the fields of science and critical literacy in Indonesia. Rahmawati and Atmojo (2022) and Mikhridinova et al. (2023) showed that students often have difficulty understanding abstract chemistry concepts, such as quantitative analysis and applying chemistry analysis methods in real contexts. The-

***Correspondence Address**
E-mail: sriadelilasari@unimed.ac.id

refore, innovative approaches to learning, including the use of technology, are needed to address this gap.

Based on the survey of analytical chemistry students, their average ability to master the material in four categories of analytical chemistry courses reached 58.31%, which is included in the moderate category (Sari et al., 2024).. These results indicate that mastery of the material is the main obstacle for students in understanding analytical chemistry concepts, causing difficulties in the learning process. Although the quality of lecturers in lectures reached 79.97% (moderate category), which indicates that lecturers carry out their duties well, several other factors need to be considered. One of them is the availability of teaching materials, which scored 57.78% (moderate category), which indicates that the available teaching materials have not fully met the needs of students to understand the material optimally (Sari et al., 2024). Therefore, further research to develop innovations in project-integrated teaching materials in analytical chemistry practicums is needed to improve students' ability to master analytical chemistry materials (Sari et al., 2024).

Preliminary studies showed that analytical chemistry students often have difficulty in understanding abstract concepts such as quantitative analysis and the application of chemical analysis methods in real contexts. This was reinforced by the survey results which showed that students' mastery of the material was classified as moderate. This gap in understanding indicates a need for more effective and engaging teaching methods. Research in chemistry education and related fields has shown that innovations in learning approaches, including the use of interactive technology and visualization, can increase student engagement and facilitate the understanding of abstract concepts and their application in real contexts. Therefore, innovation in learning approaches, including the use of technology, is needed to overcome this gap (Gyang & Adu-Gyamfi, 2024; Tursyngozhayev et al., 2024).

One solution to improve students' abilities is the development of technology-based flipbooks in analytical chemistry learning. This book utilizes interactive visual elements that can help students understand chemistry concepts that are often difficult to understand. Kurniawan et al. (2020) showed that using technology in textbooks can increase learning motivation. In addition, applying the Project-Based Learning (PjBL) model has improved students' critical thinking skills by allowing them to complete real-world problem-based projects relevant to the material being studied (Abdulrahaman et al., 2020). This combination of methods—technology-based flipbooks and PjBL models—is still limited in analytical chemistry research. Integrating these two approaches has the potential to create a more holistic learning experience, which not only enhances students' critical thinking skills and scientific literacy but also supports the goal of quality education (SDG-4) to build a more intelligent and competent society (Setiyawati, 2021; Aldraiweesh & Alturki, 2023; Indriyani, 2023).

Quality education is an important foundation for achieving sustainable development. Target 4.4 of SDG 4 emphasizes improving technical and vocational skills for decent work. In this context, the development of critical thinking skills and scientific literacy in analytical chemistry is highly relevant. These skills not only prepare students for careers in science and technology but also equip them to contribute to innovation and sustainable solutions. Moreover, the development of these skills also supports target 4.7, which is to ensure all learners acquire the knowledge and skills needed to promote sustainable development (Dian et al., 2024; Hardianto et al., 2024).

The analytical chemistry flipbook offers a new way of presenting learning materials. With interactive visual elements, the book helps students understand the abstract concepts of analytical chemistry. Technology in textbooks can improve students' problem-solving skills, which are essential in chemistry education (Rahmawati & Atmojo, 2022; Vrečič et al., 2023). In addition, analytical chemistry flipbooks also encourage students to think critically and creatively, which is very important in facing real-world challenges (Natuna et al., 2021; Hastuti et al., 2023; Siswandari, 2023).

The PjBL model places students in real situations where they must complete projects that are relevant to the material being studied. PjBL can improve students' creativity and critical thinking skills by actively involving them in learning (Sumarni & Kadarwati, 2020; Mulyani et al., 2022; Syahri et al., 2023). In the context of analytical chemistry, PjBL can be used to design projects related to the analysis of chemical substances, where students can apply the theories they have learned in actual practice (Suana et al., 2023; Arga, 2024). This function aligns with the findings that PjBL can improve students' collaboration and communication skills (Churiyah, 2023; Ummah, 2023; Khoiri et al, 2023).

Integrating analytical chemistry flipbooks with PjBL models can create a more holistic learning experience. By combining interactive

flipbooks with PjBL-based projects, students can more easily understand analytical chemistry concepts and apply them in real projects (Kurniasari, 2023; Pujaningsih et al., 2023). This approach enhances critical thinking skills and prepares students to become active and responsible citizens (Bartholomay, 2022; Hujjatusnaini et al, 2022; Arifah, 2024).

Implementing flipbooks and PjBL focuses on improving critical thinking skills and developing 21st-century skills, such as collaboration, communication, and problem-solving. PjBL can improve students' literacy, critical thinking, and collaboration skills (Smuts et al., 2021; Maasø, 2023). This is especially important in chemistry education, where students must develop relevant skills to face real-world challenges (Putra et al., 2022; Kurniasari, 2023). Thus, integrating these two elements can significantly contribute to the achievement of SDG-4, which emphasizes the importance of quality education for all (McDaniel et al., 2022; Yensy et al., 2023; Scherer, 2024). This challenge becomes even more pronounced in higher education, particularly in analytical chemistry. Students often struggle to understand abstract chemical concepts, such as quantitative analysis and applying chemical analysis methods in daily life (Muhammadi, 2023). Therefore, innovative approaches such as using technology in learning are needed to address this gap. Wiratmoko and Sampurno (2021) showed that developing e-magazines in chemistry learning can improve students' understanding of the material. These results indicate that using digital media in education can positively impact students' understanding.

Developing technology-based flipbooks in analytical chemistry education can provide significant benefits for students. These flipbooks will not only help students understand complex chemistry concepts but can also increase their learning motivation. Yosintha (2024) showed that using Kvisoft Flipbook Maker to develop teaching materials can improve students' critical thinking skills. Thus, developing PjBL-based flipbooks can be a strategic step in improving the quality of education in analytical chemistry.

Although previous studies have shown the effectiveness of using technology in chemistry learning (Kurniawan, et al., 2020; Wiratmoko & Sampurno, 2021; Dahliana, 2024; Yosintha, 2024), and the application of the Project-Based Learning model in improving critical thinking skills (Abdulrahaman et al., 2020; Syahri et al., 2023), research integrating technology-based flipbooks with the PjBL model in the context of analytical chemistry is still limited. The integration of technology and active learning models can improve the quality of education. However, the application of this integration in the field of analytical chemistry, especially through the development of PjBL-based flipbooks, has not been widely explored. This research seeks to fill the gap by developing and testing the effectiveness of PjBL-based analytical chemistry flipbooks in improving students' critical thinking skills and scientific literacy (Scherer, 2024).

However, it is important to note that research on combining technology-based flipbooks and PjBL models is still limited in analytical chemistry. Further research is needed to explore the potential integration of these two approaches in higher education contexts. Sabitri (2024) showed that problem-based learning media can improve students' critical thinking skills. Therefore, this study is expected to improve the quality of education in analytical chemistry, which is in line with SDG-4 and educational achievement in Indonesia. In order to achieve these goals, it is important to involve various stakeholders in developing and implementing PjBL-based flipbooks. Collaboration between lecturers, students, and related parties will create a practical and enjoyable learning experience. Dahliana (2024) showed that developing e-flipbooks can improve students' digital literacy. These results indicate that the use of technology in education can have a positive impact on students' skills.

Overall, developing flipbooks and implementing the project-based learning model has great potential to improve students' critical thinking skills and scientific literacy. With an interactive and relevant approach, students can more easily understand complex concepts and develop the skills needed to face challenges in everyday life (Kaske et al., 2021; Mikhridinova et al., 2023). The integration of these two elements not only supports the goal of quality education but also contributes to the achievement of SDG-4 (Hamidani, et al., 2022; Fajrina et al., 2023). In this context, it is important to develop innovative teaching materials that can help students not only understand the material but also develop the skills needed to contribute to society (Choudhary et al., 2021; Melo et al., 2021; Jumiarni, 2023). Developing technology-based teaching materials can increase motivation and engagement in learning (Adegun et al., 2020; Lestari, 2023; Setiawaty et al., 2024). Therefore, developing analytical chemistry flipbooks in analytical chemistry education should be seen as a strategic step to improve the quality of education and students' critical

thinking skills (Canto et al., 2023; Hardiyanti et al., 2023). This study aimed to develop and evaluate the effectiveness of Project-Based Learning-based analytical chemistry flipbooks in improving critical thinking skills and scientific literacy of analytical chemistry students.

METHODS

This research was quantitative research with a quasi-experimental design, involving two groups: an experimental group and a control group (Campbell & Stanley, 2015). The experimental group received treatment in the form of using a flipbook based on the Project-Based Learning (PjBL) model in learning analytical chemistry, while the control group used conventional textbooks. This study was aimed to determine the effectiveness of PjBL-based flipbooks in improving students' critical thinking skills and scientific literacy. Learning was conducted for 2 meetings. The materials used in the flipbook and textbook were adjusted to the Analytical Chemistry course syllabus. To ensure that both groups have equal initial abilities, a pretest was conducted before treatment.

The population in this study were all students who took Analytical Chemistry courses in the Chemistry Education study program in the current semester. The research sample consisted of 500 students, who were selected using purposive sampling technique based on the following inclusion criteria: (1) Registered as active participants in the Analytical Chemistry course this semester. (2) Have an educational background that is relevant to the field of chemistry.

The sample selection process was carried out by taking data from the list of course participants issued by the academic department. Furthermore, students who met the inclusion criteria were identified based on their academic history. Purposive sampling was chosen so that the sample obtained was homogeneous and relevant to the research objectives.

However, it should be recognized that the used of purposive sampling limits the generalizability of the study results. The selected sample may not fully represent the overall population of analytical chemistry students, and the results of the study may only apply to students with similar characteristics. Therefore, interpretation of the study results needs to be done with caution.

The instruments used in this study were critical thinking skills and scientific literacy tests, each consisting of 15 multiple choice questions. This test is designed to measure: (1) Understanding of analytical chemistry concepts; (2) Analytical skills; (3) Problem solving skills; (4) Application of concepts in practical contexts.

The instrument was tested for content validity by four expert lecturers in Analytical Chemistry, who assessed the suitability of content, level of difficulty, and relevance to indicators of critical thinking skills and scientific literacy. Furthermore, construct validity was tested using exploratory factor analysis. Reliability tests were conducted using Cronbach's Alpha coefficient, and the targeted value was ≥ 0.70, indicating acceptable internal consistency (Osborne, 2008).

Data collection in this study was carried out through giving pretests and posttests to both groups, namely the experimental group and the control group. The test was conducted in the form of a written exam in the classroom, with uniform time and conditions for all participants, in order to maintain fairness and accuracy of the results.

The pretest was given before the learning process began, with the aim of measuring students' initial ability to understand analytical chemistry concepts, critical thinking, and scientific literacy. Meanwhile, the posttest was given after the learning intervention was carried out for two meetings, both for groups using Project-Based Learning (PjBL) based flipbooks and groups using conventional textbooks. This test aims to evaluate the improvement of students' abilities after following the learning process with different approaches.

The data were analyzed using SPSS 16.0 for Windows software with several stages. First, the normality test was conducted using the Kolmogorov-Smirnov test to ensure that the pretest and posttest data were normally distributed (Corder & Foreman, 2014). Second, the homogeneity test was conducted using Levene's test to check the equality of variance between the experimental and control groups (Verma & Salam, 2019). Next, a paired sample t-test was used to measure the difference in the pretest and posttest average scores. If the p-value <0.05, then there is a significant difference. In addition, the n-gain test was used to measure the increase in students' abilities from pretest to posttest in three levels: low, medium, and high. With this approach, the study aims to evaluate the effectiveness of PjBL-based flipbooks in improving students' critical thinking skills and scientific literacy. N-Gain data was calculated using the formula in (Eq 1):

$$G = \frac{\text{posttest} - \text{pretest}}{\text{maximum score} - \text{pretest}} \quad \text{.....(1)}$$

Table 1 shows the n-gain score distribution.

Table 1. N-Gain Score Distribution

N-Gain Score	Category
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

RESULTS AND DISCUSSION

This study aims to evaluate the effectiveness of flipbooks in analytical chemistry learning using the PjBL model to improve students' critical thinking skills and scientific literacy to support sustainable development goals. Based on the data analysis, including normality tests, homogeneity tests, mean equality tests, independent sample t-tests, and n-gain tests, this study provides significant evidence of the positive effect of using flipbooks on improving students' critical thinking skills and scientific literacy.

The normality test analysis using the Liefors Kolmogorov-Smirnov Test showed that the pretest data in the control and experimental groups were normally distributed. The significance value of 0.216 in both groups, which is greater than 0.05, indicates that the data meets the requirements for parametric statistical analysis. This result confirms that the data distribution is symmetrical and allows the use of advanced analysis techniques. The normality test for the posttest also shows that the data distribution of the control and experimental groups remains normal after treatment. The significance value of 0.216 in both groups strengthens the validity of the data and ensures that the analysis can be carried out correctly.

The homogeneity test using the ANOVA technique revealed that the data variance between the two groups was the same. A significance value of 0.86 (>0.05) indicates no significant difference in the variance between the control and experimental groups. This equality of variance is important to ensure that the comparison results between the two groups are not influenced by factors other than the treatment given. The homogeneity test of the posttest also showed that the variance between the two groups remained homogeneous, with a significance value of 0.074 (>0.05). This homogeneity ensures that the comparison of the posttest results between the control and experimental groups is not influenced by differences in variance, thus allowing for an objective evaluation of critical thinking skills.

The pretest mean equality test using an independent sample t-test confirmed no significant difference in mean scores between the experimental and control groups. With a t-value of 0.611 and a significance of 0.05, it was concluded that both groups had equivalent initial abilities.

The first hypothesis test showed that the experimental group achieved a classical passing grade, with a Z value of 0.156, more significant than the significance value of 0.05. The Z value indicates that most students in the experimental group achieved the specified competency standards. The effectiveness of flipbooks compared to conventional textbooks was evaluated using an independent sample t-test, which showed a significant difference between the two groups with a t-value of 0.038 and a significance of less than 0.05 (Table 2). This finding indicates that flipbooks have a more significant impact on improving critical thinking skills than conventional textbooks.

Table 2. Hypothesis Test

Posttest Score	t-count	Sign	Description	Interpretation
Control Group Experimental Group	0.038	0.05	tcount < sign, H_0 is rejected	PjBL-based flipbooks are more effective than conventional textbooks in improving critical thinking skills and scientific literacy.

Figure 1 shows that both groups had almost the same initial ability, with an average pretest score of 51 for the control group and 53 for the experimental group. After learning, the average posttest score increased to 64 for the control group and 96 for the experimental group. This increase indicates that flipbooks provide a more significant contribution to critical thinking skills.

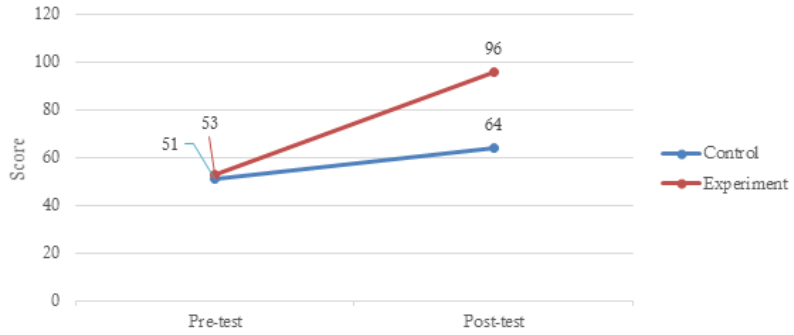

Figure 1. Students' Pretest and Posttest Scores on the Critical Thinking and Scientific Literacy Test

Based on Figure 1, an n-gain test was conducted. The n-gain analysis showed that the experimental group had a higher increase in critical thinking skills than the control group. With an n-gain of 0.9 (high category) in the experimental group and 0.63 (medium category) in the control group, this difference reflects the effectiveness of flipbooks in helping students understand the material better.

This model encourages students to actively participate in learning by completing relevant and challenging projects. The flipbook is a source of information and a tool that facilitates understanding and applying concepts in real contexts. Interactive learning experiences can increase student engagement and overall critical thinking skills (Hensley, 2024; Lees-Murdock et al., 2024)

One of the main advantages of these flipbooks is their ability to help students memorize concepts and understand and apply them in broader situations. Students who engage in project-based learning tend to have a better understanding of the material they are learning because they can see the relevance between theory and practice (Haryanti et al., 2024; Haswan et al., 2024; Winarko, 2024). These results align with the finding that project-based learning can improve critical thinking skills and problem-solving abilities, which are very important in higher education (Arga, 2024). Thus, analytical chemistry flipbooks contribute to the achievement of student-centered learning goals, where students are encouraged to be more active and independent in their learning process Adawiah et al., 2024)

Using technology in flipbooks also plays an important role in improving students' understanding of the material. Technology allows the integration of interactive elements, such as videos, animations, and simulations, which can enrich students' learning experiences (Handayani & Nurhamidah, 2024; Wang & Sitthiworachart, 2024). The use of technology in education can increase students' engagement and motivation (Afshar et al., 2024; Etemi et al., 2024). By utilizing technology, this flip book meets learning needs and supports sustainable development goals, especially in quality education and learning based on 21st-century skills (Jha et al., 2020). These results suggest that flipbooks can effectively prepare students to face the challenges of increasingly complex careers.

These flipbooks also provide an opportunity for students to learn collaboratively. In the context of PjBL, collaboration between students is essential to develop social and communication skills needed in the workplace. Social interaction in learning can improve students' understanding and skills (Arga, 2024). By working together on projects, students not only learn from the material but also from the experiences and perspectives of their peers, which can enrich the overall learning process. Therefore, integrating flipbooks with the PjBL model can create a more inclusive and collaborative learning environment (Hussein et al., 2024; None et al., 2024).

Furthermore, implementing flipbooks in the PjBL model can increase students' learning motivation. When students are involved in relevant and interesting projects, they tend to be more motivated to actively participate in the learning process (Celik, 2024). High motivation is positively related to better critical thinking skills, so it is important to create engaging and challenging learning experiences for students (Jirapanthong, 2020; Kurniasari, 2023).

Using illustrations in textbooks has proven effective in improving students' understanding (Sari, 2020). Visually appealing illustrations can help students understand complex concepts in chemistry, thereby increasing their motivation and interest in learning. Sari and Hasibuan (2023) emphasized that digital illustration media can improve students' critical thinking skills. This statement aligns with the finding that using graphic illustrations in learning can make content easier to understand (Movsisyan et al., 2021; Nonthamand, 2024; Reyes & Villanueva, 2024; Anugrahno & Nugrahanta, 2024).

This study showed that the use of illustration-based flipbooks in learning analytical chemistry, integrated with a project-based learning model, significantly improved students' critical thinking skills

and scientific literacy. These results are in line with the findings that visual illustrations in textbooks are effective in improving student understanding (Sari, 2020). Visually appealing illustrations help students understand complex chemical concepts, increasing their motivation and interest in learning (Movsisyan et al., 2021; Anugrahno & Nugrahanta, 2024). In addition, digital illustration media is proven to improve students' critical thinking skills (Sari & Hasibuan, 2023; Nonthamand, 2024; Reyes & Villanueva, 2024).

The integration of PjBL in this flipbook provides a real context for students to apply their knowledge. PjBL has been shown to improve science process skills collaboration, and communication (Almuhammadi, 2024). This approach encourages students' active engagement in learning, which results in a deeper understanding of the material and increased motivation to learn (Alotaibi, 2024; Hidayati et al., 2024; Irdalisa et al., 2024). PjBL's focus on developing critical thinking, social, and emotional skills is highly relevant to the needs of 21st century education (Nasbey et al., 2024).

This research makes a new contribution by integrating interactive illustrations in flipbooks with the PjBL model in the context of analytical chemistry. In contrast to previous studies that focus more on the use of static illustrations or PjBL separately, this study shows that the combination of both creates a more holistic and effective learning experience. Interactive flipbooks allow students to explore chemical concepts visually and independently, while PjBL provides an opportunity to apply that knowledge in real projects (Hidayati et al., 2024).

Given the limitations of illustration technology-based flipbooks, such as limited interactivity and dependence on hardware, future research needs to explore the socio-demographic characteristics of students who are best suited to this technology. For example, research could identify whether students with visual learning styles or students who have better access to technology benefit more from using these flipbooks. Identifying specific student populations that benefit from these flipbooks would provide valuable insights for educators and policy makers (Fathonah et al., 2024).

This study has some limitations. First, the use of purposive sampling limits the generalizability of the results. Future research could use random sampling techniques to improve population representation. Second, this study only measured critical thinking skills and scientific literacy. Future research can explore the impact of flipbooks on other aspects, such as learning motivation, attitude towards chemistry, and problem solving skills. Third, this study did not explore the interaction between student characteristics and flipbook effectiveness. Future research can use a more complex research design to identify factors that moderate flipbook effectiveness (Zhong et al., 2024).

In addition, future research could explore the use of more advanced technologies in flipbooks, such as augmented reality (AR) or virtual reality (VR), to enhance interactivity and student engagement. Research could also explore the use of flipbooks in online or blended learning contexts, as well as their impact on collaborative learning.

This study provides empirical evidence on the effectiveness of illustration-based flipbooks and PjBL in improving students' critical thinking skills and scientific literacy. By addressing the limitations of this study and exploring future research directions, we can develop more innovative and effective learning approaches to improve the quality of chemistry education (Wilson et al., 2024).

CONCLUSION

This study concluded that Project-Based Learning-based flipbooks were significantly more effective than conventional textbooks in improving students' critical thinking skills and scientific literacy. Statistical tests showed that the data were normally distributed (significance value 0.216), homogeneous variance (0.074), and significant differences between the experimental and control groups ($t = 0.038$, $p < 0.05$). The increase in n-gain in the experimental group reached 0.9 (high category), compared to 0.63 (moderate category) in the control group. These findings support using the results of this study confirmed the superiority of PjBL-based flipbooks in significantly improving students' critical thinking skills and scientific literacy compared to conventional textbooks. Statistical data support (normal distribution, homogeneous variance, significant differences between groups, and high n-gain in the experimental group) encourages the adoption of PjBL-based flipbooks as an effective learning strategy to achieve quality education according to SDG-4. Future research is recommended to expand the implementation of PjBL-based flipbooks to various subjects and levels of education, analyze the most effective design and PjBL elements, compare them with other innovations, conduct long-term studies, and examine the factors that influence their success.

ACKNOWLEDGEMENTS

This research can be carried out well thanks to the assistance of various parties. The researcher would like to thank Universitas Negeri Medan through the

Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) for research funds with contract number 0252 / UN33.8 / PPKM / PPT / 2024. The researcher also thanks the Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, for the facilities and infrastructure provided during the research. Thank you to all students in the Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan as respondents in this study.

REFERENCES

Abdulrahaman, M. D., Фарук, H., Oloyede, A. A., Surajudeen-Bakinde, N. T., Olawoyin, L. A., Mejabi, O. V, … Azeez, A. L. (2020). Multimedia Tools in the Teaching and Learning Processes: A Systematic Review. *Heliyon*, *6*(11), e05312.

Adawiah, R., Ruchliyadi, D. A., & Halidi, W. (2024). A Combination of the Project Based Learning Model and Value Clarification Technique in Improving Students' Critical Thinking Skills. *Indonesian Journal of Educational Development (IJED)*, *5*(1), 68–78.

Adegun, A. A., Ogundokun, R. O., Adebiyi, M. O., & Asani, E. O. (2020). CAD-Based Machine Learning Project for Reducing Human-Factor-Related Errors in Medical Image Analysis. *Handbook of Research on the Role of Human Factors in IT Project Management* , 164–172.

Afshar, M., Zarei, A., Moghaddam, M. R., & Shoorei, H. (2024). Flipped and Peer-Assisted Teaching: A New Model in Virtual Anatomy Education. *BMC Medical Education*, *24*(1).

Aldraiweesh, A., & Alturki, U. (2023). Exploring Factors Influencing the Acceptance of E-Learning and Students' Cooperation Skills in Higher Education. *Sustainability*, *15*(12), 9363.

Almuhammadi, A. (2024). Examining the Integration of 21st Century Skills in EFL Instruction: A Case Study of Selected Saudi Universities. *English Language Teaching*, *17*(6), 45.

Alotaibi, M. S. (2024). Game-Based Learning in Early Childhood Education: A Systematic Review and Meta-Analysis. *Frontiers in Psychology*, *15*.

Anugrahno, M. H., & Nugrahanta, G. A. (2024). Development of Traditional Game Book as A Means of Improving The Integrity Character of 10-12 Years Old Children. *Jurnal Pendidikan Glasser*, *8*(1), 1–14.

Arga, H. S. P. (2024). Sustainable Lifestyle Project: An Empirical Study. *International Conference on Teaching, Learning and Technology* , 106–113.

Arifah, F. (2024). The Effect of the Project-Based Learning Model on Interest in Learning Arabic Language. *International Conference on Environmental Learning Educational Technologies* , 199–211.

Bartholomay, D. J. (2022). *Working Toward an Equity-Based Model for Volunteering and Service-Learning Projects in Higher Education*.

Campbell, D. T., & Stanley, J. C. (2015). *Experimental and Quasi-Experimental Designs for Research*. Ravenio Books.

Canto, C. A. R. D. L., Silveira, M. S., Piana, V. J., & Endres, C. M. (2023). Project-Based Learning: A Scope Review to Support the Teaching Process in Higher Education. *Seven Editora*.

Celik, I. (2024). The Affordances of Artificial Intelligence-Based Tools for Supporting 21st-Century Skills: *Australasian Journal of Educational Technology*.

Chen, X., Zou, D., Xie, H., & Wang, F. L. (2024). Technology-Enhanced Higher Education: Text Mining and Bibliometrics. *Heliyon*, *10*(4), e25776.

Choudhary, F. R., Ahmed, S., Sultan, S., & Khushnood, S. (2021). Comparative Study of 21st Century Skills of Science Teachers and Students of Formal and Non-Formal Educational Institutes. *Review of Education Administration and Law*, *4*(1), 231–241.

Churiyah, M. (2023). Project Based Learning Interactive E-Book: A Solution to Self Regulated Learning and Student Learning Outcomes. *BISTIC Business Innovation Sustainability and Technology International Conference (BISTIC 2023)*, 132–142.

Corder, G. W., & Foreman, D. I. (2014). *Nonparametric Statistics A Step-by-Step Approach*. Wiley.

Dahliana, D. (2024). Educational Comics Based on Creative Problem Solving With the Aid of Kvisoft Flipbook Maker Pro for Elementary School. *Education Achievement Journal of Science and Research*, 1–6.

Dian, A., Habiddin, H., Dasna, I. W., & Rahayu, S. (2024). Scientific Literacy in Science Instruction: Media and Teaching Approach Employed. *Education and Human Development Journal*, *8*(3), 52–63.

Endaryati, S. A., Atmojo, I. R. W., Slamet, St. Y., & Suryandari, K. C. (2021). Analisis E-Modul Flipbook Berbasis Problem Based Learning Untuk Memberdayakan Keterampilan Berpikir Kritis Pembelajaran IPA Sekolah Dasar. *Dwija Cendekia Jurnal Riset Pedagogik*, *5*(2), 300.

Etemi, B. P., Uzunboylu, H., Latifi, S., & Abdigapbarova, U. (2024). The Effect of the Flipped Learning Approach on Engineering Students' Technology Acceptance and Self-Directed Learning Perception. *Sustainability*, *16*(2), 774.

Fajrina, S., Lufri, L., Ahda, Y., & Alberida, H. (2023). Validity of Project Learning Model Based on STEMS to Improve Creativity in the 21st Century. *In 3rd International Conference on Biology, Science and Education (IcoBioSE 2021)*, 9–17.

Fathonah, S., Cahyono, E., Haryani, S., Sarwi, S., & Lestari, N. H. (2024). Application of Multirepresentation-Based Creative Problem-Solving Learning Models to Improve Critical and Creative Thinking Skills for Students. *International Journal of Cognitive Research in Science, Engineer-*

ing and Education, *12*(1), 185–200.

Gyang, N. O., & Adu-Gyamfi, K. (2024). Teaching Organic Chemistry to Upper-Secondary Students Hasn't Been Easy: A Conversation With Teachers and Students on Barriers. *Gamtamokslinis Ugdymas / Natural Science Education*, *21*(1), 18–34.

Hamidani, K., Neo, T.-K., & Perumal, V. (2022). Conceptual Framework to Elicit Behavioral Engagement via Project Based Experiential Learning. *In 2nd International Conference on Creative Multimedia 2022*, 51–58.

Handayani, D., & Nurhamidah, N. (2024). The Development of Student Soft Skills Through the Integration of PJBL STEAM Learning in the Organic Chemistry 1 Topic of Hydrocarbons. *Jurnal Pendidikan Kimia Indonesia*, *8*(1), 29–38.

Hardianto, H., Mahanal, S., Susanto, H., & Prabaningtyas, S. (2024). Protist Literacy: A Novel Concept of Protist Learning in Higher Education. *Eurasia Journal of Mathematics Science and Technology Education*, *20*(2), em2399.

Hardiyanti, W. E., Arif, R. M., Ahmad, M., Hesti, & Ekadayanti, W. (2023). Applying Gardening Projects to Improve Scientific Knowledge and Collaboration in Early Childhood Education. *In 1st UMSurabaya Multidisciplinary International Conference 2021 (MICon 2021)* , 597–607.

Haryanti, Y., Taruddin, T., Uslan, U., Ginanjar, G., & Azizah, W. (2024). *Learning Science Is Easy and Fun Using Models Project-Based Learning*. *1*(1), 30–35.

Hastuti, Ambiyar, A., Jalinus, N., Syahril, S., & Syah, N. (2023). Project-Based Learning to Enhance Creativity and Learning Outcomes. *In 9th International Conference on Technical and Vocational Education and Training (ICTVET 2022)*, 67–73.

Haswan, H., Ridzal, D. A., & Rosnawati, V. (2024). Analysis of Students Creative Thinking Abilities Through Project-Based Learning in Environmental Knowledge Courses. *Jurnal Pijar Mipa*, *19*(1), 33–36.

Hensley, M. S., Burrows, N. L., Galerneau, A. J., Bekkala, A. P., & Hungwe, K. N. (2024). Investigating the Impact of RAMP-Based Safety Instruction on Student Learning in an Organic Chemistry Lab Course. *Journal of Chemical Education*, *101*(6), 2203–2214.

Hidayati, K., Rahmawati, A., & Wijayanto, D. S. (2024a). Development of Learning Media to Improve Critical Thinking Skills and Creativity of Vocational Students. *International Journal of Social Service and Research*, *4*(03), 716–724.

Hidayati, K., Rahmawati, A., & Wijayanto, D. S. (2024b). Development of Learning Media to Improve Critical Thinking Skills and Creativity of Vocational Students. *International Journal of Social Service and Research*, *4*(03), 716–724.

Hujjatusnaini, N., Corebima, A. D., Prawiro, S. R., & Gofur, A. (2022). The effect of blended project-based learning integrated with 21st-century skills on pre-service biology teachers' higher-order thinking skills. *Jurnal Pendidikan IPA Indonesia*, *11*(1), 104-118.

Hussein, S., Khoiruzzadittaqwa, M., Luthfiyah, L., & Alhaq, M. M. (2024). The Effectiveness of Project-Based Learning and Problem-Based Learning in Improving Student Achievement and Involvement in Learning Mathematics. *International Journal of Mathematics and Mathematics Education*, 89–99.

Indriyani, D. (2023). The Impact of Project-Based Learning to Build Student Civic Engagement in the Digital Age. *In 4th Annual Civic Education Conference (ACEC 2022)*, 120–125.

Irdalisa, I., Zulherman, Z., Elvianasti, M., Widodo, S. A., & Hanum, E. (2024). Effectiveness of Project-Based Learning on STEAM-Based student's worksheet analysis With Ecoprint Technique. *International Journal of Educational Methodology*, *volume-10-2024*(volume-10-issue-1-february-2024), 923–935.

Jirapanthong, W. (2020). A Tool for Supporting the Evaluation of Active Learning Activities. *In Advances in Swarm Intelligence: 11th International Conference*, 476–484.

Jumiarni, D. (2023). Development of Biotechnology E-Module Based on Integrated Project Based Learning With STEM Approach. *In Online Conference of Education Research International (OCERI 2023)*, 181–188.

Kaske, R., Connaher, B., & Mahfuz, M. U. (2021). Smart Greenhouse Project: A Sustainability-Focused Learning Experience for Undergraduates. *Sustainable Energy for Smart Cities: Second EAI International Conference*, 53–62.

Khoiri, N., Ristanto, S., & Kurniawan, A. F. (2023). Project-based learning via traditional game in physics learning: Its impact on critical thinking, creative thinking, and collaborative skills. *Jurnal Pendidikan IPA Indonesia*, *12*(2), 286-292.

Kurniasari, I. (2023). Designing Learning Materials Oriented Towards Project-Based Learning on Statistics for 7th-Grade Students. *In International Joint Conference on Arts and Humanities 2023*, 1935–1954.

Kurniawan, D. A., Astalini, A., Winda, F. R., Heldalia, H., & Kartina, L. (2020). The Correlation Between Student Perceptions of the Use of E-Modules With Students' Basic Science Process Skills. *Jpi (Jurnal Pendidikan Indonesia)*, *9*(4), 719.

Lees-Murdock, D. J., Khan, D., Irwin, R., Graham, J., Hinch, V., O'Hagan, B., & McClean, S. (2024). Assessing the Efficacy of Active Learning to Support Student Performance Across Undergraduate Programmes in Biomedical Science. *British Journal of Biomedical Science*, *81*.

Lestari, N. D. (2023). Accounting Teacher's Perception of Project-Based Learning. *Online Conference of Education Research International (OCERI 2023)*, 426–441.

Luthfi, A. (2023). Involvement of Elementary School Students Through the Application of the

STEAM With Project-Base Learning. *International Conference on Learning and Advanced Education (ICOLAE 2022)*, 92–103.

Maasø, A. (2023). Problem-Based Peer Group Mentoring and Organisational Learning. *Faculty Peer Group Mentoring in Higher Education: Developing Collegiality through Organised Supportive Collaboration*, 113–130.

McDaniel, S. L., Hall, L. J., & Kraemer, B. K. (2022). Exploring Extracurricular Clubs for Building Social Competence of Students With Autism. *Frontiers in Psychiatry*, *13*.

Melo, A. M. D. de, Balula, A., Liberato, D., Silva, C., Amaral, P., Negrusa, A., … Fleşeriu, C. (2021). Creating Collaborative Research Opportunities at a Distance: From Porto to Cluj-Napoca. *International Conference on Technology and Innovation in Learning, Teaching and Education*, 380–388.

Mikhridinova, N., Ngereja, B. J., Hussein, B., Petegem, W. V, Olaso, J. R. O., & Wolff, C. (2023). Competence-Based Support for Project-Based Learning in Virtual Settings. *International Conference on Interactive Collaborative Learning*, 246–257.

Movsisyan, A., Arnold, L., Copeland, L., Evans, R., Littlecott, H., Moore, G., … Rehfuess, E. (2021). Adapting evidence-informed population health interventions for new contexts: a scoping review of current practice. *Health Research Policy and Systems*, *19*, 1–19.

Muhammadi, M. (2023). Development of Teaching Materials Assisted by the Kvisoft Flipbook Maker Application to Improve Students Critical Thinking Skills. *Jurnal Penelitian Pendidikan Ipa*, *9*(SpecialIssue), 865–871.

Mulyani, E. A., Alpusari, M., Permana, D., Kurniaman, O., Sari, I. K., Noviana, E., & Putra, E. D. (2022). Needs Analysis for the Development of Digital Materials for Indonesian Language Skills Subject Based on Melayu Culture for PGSD Students, Universitas Riau. *5th International Conference on Language, Literature, and Education (ICLLE-5 2022)*, 257–264.

Nasbey, H., Apriliani, N. P., Kurniawan, A. F., Samsudin, A., & Fadlan, A. (2024). The Effectiveness of the Dilemma-Steam Learning Model Based on Motion Graphic Videos in the Subject of Parabolic Motion. *Journal of Physics Conference Series*, *2866*(1), 012118.

Natuna, D. A., Putra, M. J. A., & Azhar, A. (2021). Teachers' Performance in Online Learning During Covid-19 Outbreak: An Analysis Based on 21st Century Proficiency. *International Journal of Educational Best Practices*, *5*(2), 197.

None, N., Yuliana, Y., Abadi, A. M., None, N., Hendrowibowo, L., None, N., … None, N. (2024). Characteristics of the Mobile Problem Based Learning Flipped Classroom (mPBLFC) Mathematics Learning Model: A Systematic Literature Review. *Perspectives of Science and Education*, *68*(2), 261–277.

Nonthamand, N. (2024). Designing the Video-Based Learning Environments Using Workflow and Scaffolding to Enhance Self-Instructional Video Production Ability of Pre-Service Teacher. *Contemporary Educational Technology*, *16*(1), ep492.

Osborne, J. W. (2008). *Best Practices in Quantitative Methods*. SAGE Publications.

Permana, M. P., & Syahruzah, J. K. (2022). Making Learning Media for HOTS-Based Transmission Course. *1st UPY International Conference on Education and Social Science* , 435–443.

Pujaningsih, F. B., Astalini, A., Wibowo, T. H., Jailani, S. M., & Anggraini, L. (2023). Analysis of Student Responses to the Application of the Project Based Learning (PJBL) Model in the Introduction to Solid State Physics Course. *Mathematics and Science Education International Seminar 2021 (MASEIS 2021)* , 90–96.

Putra, I. N. A. J., Budiarta, L. G. R., & Adnyayanti, N. L. P. E. (2022). Developing Authentic Assessment Rubric Based on HOTS Learning Activities for EFL Teachers. *2nd International Conference on Languages and Arts across Cultures*, 155–164.

Rahmawati, R. D., & Atmojo, S. E. (2022). Improving the Problem-Solving Ability of Prospective Elementary School Teacher Candidates Through Blended Project-Based Learning. *1st UPY International Conference on Education and Social Science*, 227–234.

Reyes, R. L., & Villanueva, J. A. (2024). Narrative-Based Concept Representations: Fostering Visual Cognition in the Introductory Chemistry Classroom. *Journal of Chemical Education*, *101*(3), 1106–1119.

Sabitri, Z. (2024). The Implementation of Augmented Reality-Based Flipbook Learning Media in Improving Vocational School Students' Critical Thinking Skills in the Era of Society 5.0. *Jurnal Pendidikan Teknologi Kejuruan*, *7*(1), 22–31.

Sari, S. A. (2020). Pengembangan handout materi sistem koloid berbasis guided note taking untuk meningkatkan hasil belajar dan respon siswa kelas XI SMA. *Jipi (Jurnal Ipa Dan Pembelajaran Ipa)*, *4*(1), 41–59.

Sari, S. A., Dewi, R. S., Saputra, K., Kembaren, A., & Hasibuan, H. (2024). Analysis of Learning Difficulties of Students Majoring in Chemistry Analytical Chemistry Course. *Proceeding of International Conference on Chemistry and Chemical Eduction (ICCCE)*, *1*(2), 1–9.

Sari, S. A., & Hasibuan, H. (2023). The Development of Flip-Based Chemistry Illustration. *Prosiding Seminar Nasional Kimia*, *2*(1), 71–80.

Scherer, P. (2024). *Fostering Basic Mathematical Competencies: Concepts and Materials for Teachers and Students for Understanding Place Value in Inclusive Settings*.

Setiawaty, S., Lukman, I. R., Imanda, R., Sudirman, S., & Rauzatuzzikrina, R. (2024). Integrating Mobile Augmented Reality Applications Through

Inquiry Learning to Improve Students' Science Process Skills and Concept Mastery. *Jurnal Pendidikan IPA Indonesia*, *13*(1), 90–102.

Setiyawati, S. D. (2021). Report on the Creation of the "Sense of Vision" Application Using Android-Based Augmented Reality Technology. *J. Soft. Eng. Inf. Comm. Tech.*, *2*(1), 17–26.

Siswandari, P. (2023). Mathematics and ICT Integrative Learning to Develop Students' Numeracy Skills in Elementary School. *7th International Symposium on Mathematics Education and Innovation (ISMEI 2022)* , 93–102.

Smuts, H., Jordaan, M., & Smuts, C. (2021). Towards a Knowledge Operationalisation Model for Service Learning in Community Projects in Higher Education. *Knowledge Management in Organizations: 15th International Conference*, 41–53.

Suana, W., Andra, D., Permadi, D., & Putri, N. M. A. A. (2023). A Systematic Review of Project-Based Blended Learning as an Innovative Teaching Model. *4th International Conference on Progressive Education 2022*, 138–148.

Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21.

Syahri, B., Ambiyar, A., Syah, N., & Syahril, S. (2023). Increasing Student Cooperation Through the Application of Project-Based Learning in Lathe Machining Engineering Course. *9th International Conference on Technical and Vocational Education and Training*, 35–42.

Tursyngozhayev, K., Kavak, N., & Akhmetov, N. K. (2024). Enhancing Chemistry Education for Students Through a Novel Card Game: Compound Chain. *Journal of Chemical Education*, *101*(3), 1367–1372.

Ummah, F. (2023). Learning Beyond the Classroom: An Effective Way Understanding the Hospital Health Promotion Among Hospital Administration Students. *2nd International Conference of Health Innovation and Technology*, 132–137.

Verma, J. P., & Salam, A.-S. G. A. (2019). *Testing Statistical Assumptions in Research*. Wiley.

Vrečič, M., Zupanc, A., & Hmelak, M. (2023). Innovative Forms of Learning and Teaching: Students' Perspective. *Perspectives on Teacher Education and Development*, 177–195.

Wang, X., & Sitthiworachart, J. (2024). *Effects of Project-Based Learning on Students' Learning Performance and Engagement in Computer Science*.

Wilson, S., Tolley, C., Mc Ardle, R., Lawson, L., Beswick, E., Hassan, N., … Slight, S. (2024). Recommendations to advance digital health equity: a systematic review of qualitative studies. *NPJ Digital Medicine*, *7*(1), 173.

Winarko, G. C. (2024). Project-Based Learning With Scratch to Improve Students' Creative Thinking Ability: Systematic Literature Review. *Griya Journal of Mathematics Education and Application*, *4*(2), 190–196.

Wiratmoko, C., & Sampurno, M. B. T. (2021). The Enchantment of Tiktok as Gen Z Creativity Place in Sma Negeri 2 Surabaya's Batik Motifs Online Exhibition. *Education and Human Development Journal*, *6*(2), 1–11.

Yensy, N. A., Danim, S., & Susanta, A. (2023). Increasing the Students' Understanding of Analyzing Data Through Project-Based Learning. *Mathematics and Science Education International Seminar 2021*, 265–272.

Yosintha, R. (2024). Developing a Flipbook for Introduction to English Grammar Course With Project-Based Learning Approach. *Langkawi Journal of the Association for Arabic and English*, 66.

Zhong, J., Ismail, L., & Ahmad, N. K. (2024). Factors Influencing Engagement in Project-Based Learning Among College EFL Speakers. *International Journal of Learning, Teaching and Educational Research*, *23*(1), 318–338.