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Deep Learning-Based Animated Media Integration: Effects on Elementary School Students' Understanding of Science Concepts

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ABSTRACT

This study was motivated by the need for more interactive and adaptive elementary science instruction in the digital era, especially to help students grasp abstract scientific concepts. The purpose was to investigate the effect of deep learning-based animated media on students' science conceptions, the capacity of the media to visually represent contents and simultaneously consider individual learning needs, and the effectiveness of the media compared to that of mainly traditional instruction. The research was a quasi-experimental design, Nonrandomized Control-Group Pretest-Posttest design which involved 50 students of grade four at SDN Sukarahayu 02. The experimental group studied the water cycle via deep learning-based animated media, whereas the control group was taught through conventional method. The investigation was based on a 20-item multiple-choice test that was given as pretest and posttest and a student perception questionnaire. The results indicated similar initial abilities in both groups, but the experimental group showed greater improvement, with an average posttest score of 82.75 and an N-Gain of 30.40, compared with 68.45 and 16.65 in the control group. The post-test score was significantly different by Mann-Whitney test ($p = 0.012$). The students contributed to the positive perception: 88% considered the lessons more interesting, 84% noted that it was easier to understand the content, 88% said that they had been assisted in visualizing abstract ideas, and 80% recorded an increase in motivation to participate actively in learning. These findings suggest that deep learning-based animated media effectively improves science concept understanding and supports more interactive learning than conventional approaches.

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1. INTRODUCTION

The Fourth Industrial Revolution has been fomenting transformative change in education, not just changing how teaching and learning are carried out, but also necessitating schools be more responsive to technological advances and to the characteristics of students. The growth of digital is pushing learning out of traditional methods and into approaches that are more immersive, collaborative and informed by data (Bryda & Costa, 2023; Mhlongo et al., 2023). As a result, innovation in the learning process has become a real necessity rather than a mere option (Mierlo & Beers, 2020; Salazar, 2023). In this context, the use of Artificial Intelligence (AI) is increasingly viewed as an important strategy for improving learning quality, because AI can help teachers deliver learning experiences that are more relevant, focused, and aligned with students' needs (Salem, 2024). One rapidly developing branch of AI is deep learning—an approach that can process data and identify students' learning patterns to generate more personalized learning recommendations, such as adjusting the difficulty level of materials, providing automated feedback, or suggesting learning activities that match students' strengths and weaknesses (Kanchon et al., 2024; Murtaza et al., 2022). Therefore, integrating deep learning into instructional media has become a strategic issue, especially at the elementary level, where students need visual support and concrete activities to better understand concepts—particularly science concepts that are often abstract.

Understanding of science concepts among elementary school students is still an challenge. From the initial observations at SDN Sukarahayu 02, 60% of upper grade students had not yet reached the Minimum Mastery Criterion of 75. This result implies science teaching has not adequately facilitated conceptual processing in students and their learning outcome is low and varied. A number of related, though separate, factors contribute to this limited understanding. Instructionality remains relatively traditional and teacher-centered, as students are informed rather than guided to explore, reason, and build concepts through meaningful learning experiences (Alguacil et al., 2024). First they're being told what to do, and upon completion of this task, they may in some cases, be given a question or two related to the task (Wieselmann et al., 2019). In addition, these are few studies on the application of modern media in general and the media of animation in particular in the teaching and learning of science is an abstract and complex, making use of visualisation, simulation, and concrete materials in order to help learners to a better understanding of those phenomena that are invisible for human eyes. Third, the learning has not been designed to adapt to each student; students have different cognitive abilities and learning preferences, but they are usually given the same materials and treatment, with slow learners getting left behind and the fast learners feel they are being under challenged (El-Sabagh, 2021; Morze et al., 2021). As a result, the understanding is superficial, they tend to cram, and they also have difficulties in applying the learned concepts into other new situations. This problem is particularly pressing because understanding of science concepts in the early years is the basis for critical thinking and scientific literacy at higher levels of education.

The solution proposed in this study is the integration of deep learning-based animated media as an adaptive learning innovation to improve elementary students' science concept understanding. Animated media was chosen because it can make abstract ideas more concrete through motion-based visualization, simulations, illustrations, and engaging narration, helping students build mental models of scientific phenomena (Skulmowski, 2024; Skulmowski & Xu, 2022). However, to ensure the media does not remain one-way and generic, deep learning is used to make it adaptive and personalized. Deep learning is able to recognize outputs of students' learning patterns from basic interaction data such as quiz answers, duration of study, error rate, or which sections of the material they frequently revisit (Gao, 2025; Y. Lin et al., 2025). Based on these patterns, the system can modify learning routes, for instance, by reinforcing unmastered concepts, suggesting more explanatory animations, offering tiered practice, or providing particular feedback based on students' errors. In a similar way, the animated media is not only colorful but also responds to the learning of students (Fatchurahman et al., 2022; Utaminingsih et al., 2024). This method would overcome the constraints of traditional teaching, empower the role of media as a means of knowledge, and assist educators in accommodating the wide range of student capabilities to deliver more individualized and richer learning experiences.

Several theories and empirical results imply that animation combined with deep learning-based personalization may be more effective for understanding science concepts. In principle, animated visual media would be consistent with learning theories suggesting concrete representation as appropriate for elementary students. Animation contributes to decreasing cognitive load in cases where students have to visualize intricate processes, such as state of matter change, water cycle, or energy flow, because it can be dynamically displayed, thus cause-effect relations are more easily understood. Studies have also proven that animation works for illustrating abstract ideas and strengthening understanding in science concepts (Mou, 2023; Strømme & Mork, 2021). Other reports have indicated motion-graphic animated videos successfully improve science understanding and learning outcomes, consolidating motivation to expect that attractive media maintain attention, motivation, and retention (Hanif, 2020). At the same time, deep learning as an AI technique will enable adaptive learning to enhance the quality of instruction through content personalization and feedback. Cao & Huang (2025) point to the possibility of deep learning improving the quality of learning, however they do not specifically link it to animation. It also aligns with the notion of differentiated instruction in which learning should be tailored to students' readiness, interests, and learning profiles in order to achieve the best results of learning. In general, these findings suggest that the use of animated information technology combined with deep learning method is consistent with visual-based learning theory, as well as is consistent with research-based adaptivity and personalization findings in TEL (Barut et al., 2022; Qusheh et al., 2021).

Overall, this study shares common ground with earlier research in emphasizing the use of visual and interactive learning technologies to improve the learning experience for elementary students—particularly by using representations that help students understand abstract content and by increasing engagement, motivation, and retention (Annetta et al., 2024; Kuznetcova et al., 2025). However, it also differs in clear ways. Annetta et al. put more emphasis on enhancing scientific literacy with spatial computing (reading comprehension and vocabulary), this work focuses on enhancing understanding of science concepts via deep learning-animated media evaluated through a quasi-experimental design. Kuznetcova is oriented toward civic learning through low-tech immersive storytelling within a participatory design case study, while this study evaluates the effectiveness of adaptive science animation media and student perceptions quantitatively. Matovu et al. (2023) present a systematic review of IVR research (2016–2020) with inconsistent results, but this study represents to our knowledge the first empirical classroom study demonstrating more consistent and larger positive effects for the experimental group, and it relates those results to adaptive media characteristics including staged modules, simulation controls, progress monitoring, and an AI assistant.

Based on this background and the identified research gap, the aim of this study is to analyze the impact of integrating deep learning-based animated media on elementary students' understanding of science concepts. It is an attempt to find out if media can make content visually available and at the same time be responsive to the learner's needs and if it can enhance the understanding of concepts better than presentation of the content that is for the most part conventional. Beyond measuring cognitive outcomes such as conceptual understanding and achievement of the KKM, this study may also offer insight into how adaptive media can reduce gaps in student ability by providing more personalized learning support. The novelty of this research lies in developing science animation media that is not only visual and interactive, but also designed to be adaptive through a deep learning approach to support personalized learning for elementary students. Unlike previous studies that emphasize spatial computing for science literacy (Annetta et al., 2024), low-tech immersive storytelling for civic learning (Kuznetcova et al., 2025), or broader IVR reviews with mixed findings (Matovu et al., 2023), this study specifically proposes an adaptive science animation model that combines visualization of scientific processes (the water cycle), simulation control, progress monitoring, and AI-assisted scaffolding that responds more directly to individual needs.

The anticipated contribution of this study encompasses two fields of research. First, it provides practical contribution to teachers by giving them suggestions in designing and constructing learning media in elementary classroom especially for science topics that need visualizing and process-oriented

elaborations. Theoretically, it contributes to the discourse on how deep learning can be supported in learning media, which is still in its infancy at elementary level in terms of its combination with animation. In the end, it is expected that this research can be owed as a reference to the further development of an adaptive animated media which is more effective, to the improvement of student's understanding on science concept, and to the support of the learning transformation in digital education era.

2. METHODS

The research was planned as a quasi experimental Nonrandomized Control-Group Pretest-Posttest design (Cresswell, 2009). This design was chosen because of the inability to completely randomize the participants. There was an experimental group and a control group. To establish their baseline skills, the two groups took a pretest. The experimental group was then instructed by the animation media based on deep learning while the control group was taught by the traditional way. After the treatment, the groups completed a post-test to investigate whether there were any improvements in prior knowledge and acquired knowledge of science concepts as a result of the teaching-learning process. The research of The study was conducted on SDN Sukarahayu 02 as class IV for the school year of 2024/2025 consisting of 50 students. Total 25 students of IV A section were taken as an experimental group and that of IV B section as a control group. The participants were chosen by purposive sampling with a specific consideration, in particular, that the two classes were deemed to possess relatively homogeneous characteristics and could thus be seen as comparable.

Three tools were employed, a science concept understanding test, a student perception questionnaire and an observation sheet. The test of concept understanding was comprised of 20 validated and reliable multiple-choice items that addressed cognitive levels ranging from C1 to C4. The student perception questionnaire was a Likert scale consisting of 15 statement to capture students responses towards the learning media. An observation sheet was utilized to document student participation in class activities as well, which enabled the investigator to observe students' engagement at the whole-class level during the intervention. The research procedure was run in two stages: a two-phase preparation and application phase, and a final review analysis. In the preparation phase the researcher created the deep learning-based animated media, developed the research instruments, and piloted the materials and tools. The process involved the administration of pretest to both the groups, treatment for 8 sessions, and the posttest. Inferential statistics were employed in the analysis phase processes the quantitative data to identify differences of science concept understanding between the experimental and control groups. Data analysis techniques included the Kolmogorov-Smirnov normality test to examine data distribution, Levene's test to confirm homogeneity of variance between groups, and the Mann-Whitney test (SPSS 25.0) to test for differences in science concept understanding between the experimental and control groups. Through these procedures and analyses, the study was expected to produce valid evidence regarding the effect of deep learning-based animated media on fourth-grade students' understanding of science concepts.

3. FINDINGS AND DISCUSSION

The study began by measuring students' baseline ability through a pretest administered to both the experimental and control groups to ensure that the two groups started from relatively comparable conditions. The intervention was delivered as deep learning-based animated media to the experimental group, and the control group did not receive this treatment. After the learning sessions were completed, a posttest was administered to examine gains in science concept understanding, and a student perception questionnaire was distributed to capture students' responses to the use of the media. The pretest and posttest results from this study are presented in Table 1.

Table 1. Hasil Pretest dan Posttest Kelompok Eksperimen dan Kontrol

Group	Test	Mean	Std. Deviasi	Minimum Score	Maximum Score	N-Gain
Experimental	Pretest	52,35	7,89	40	65	-
	Posttest	82,75	6,45	70	95	30,40
Control	Pretest	51,80	6,95	45	65	-
	Posttest	68,45	7,12	55	80	16,65

As shown in Table 1, the two groups did not differ significantly in their mean pretest scores. After the intervention, the experimental group demonstrated larger improvement with a N-Gain value of 30.40, while the control group gained only 16.65 points. To make clearer the comparison of gains in understanding of science concepts between the two groups, the data in Table 1 were plotted in Figure 1.

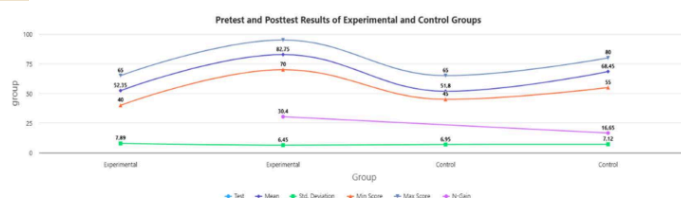


Figure 1. Comparison of Mean Pretest and Posttest Scores

Figure 1 displays a side-by-side comparison of the pretest and posttest mean scores, standard deviations, minimum-maximum scores, and N-Gain for the experimental and control group. The two groups have comparable mean pretest scores; nevertheless, the experimental group has a much greater variance in both the mean posttest score and N-Gain after the treatment, with the control group having the lesser gains. This suggests that the enhancement of students' understanding in science concepts was more in the experimental group as compared to group. The prerequisite tests and hypothesis testing were implemented to test whether this difference is significant, which is shown in Table 2.

Table 2. Statistical Test Results

Statistical Test	Significance	Decision
Kolmogorov-Smirnov (Experimental)	0.072	Data are normally distributed
Kolmogorov-Smirnov (Control)	0.085	Data are normally distributed
Levene's Test	0.21	Variances are homogeneous
Mann-Whitney Test	0.012	H ₀ rejected

The results of the normality test (Kolmogorov-Smirnov) are summarized in Table 2, but 0.072 and 0.085, respectively, for the experimental group and the control group. Both values exceed the level requirement of 0.05, which implies that the data is normally distributed. The significance value of Levene's test for homogeneity was 0.210 (> 0.05), indicating homogeneous variances. The result of the posttest scores Mann-Whitney test is significance value of 0.012 (< 0.05). This suggests that H₀ is rejected, and H_a is accepted which means that there is a statistically significant difference in the science concept understanding between the experimental and control group. In addition to investigating increase in science concept understanding, students' responses to the media were also examined with a perception questionnaire, see Table 3.

Table 3. Student Perception Questionnaire Results on Deep Learning-Based Animated Media

Statement	Agree	Total	Percentage (%)
The media makes learning more engaging	22	25	88
The material is easier to understand	21	25	84
The media helps visualize abstract concepts	22	25	88
The media motivates students to learn more actively	20	25	80

The student survey on perception results suggests that: (1) The bulk of the students, 88%, had agreed that the media made learning more interesting, (2) 84% felt that the content was simplified, (3) 88% believed that the media assisted them in visualizing abstract ideas, and (4) 80% were of the opinion that it instilled them to be more active in learning.

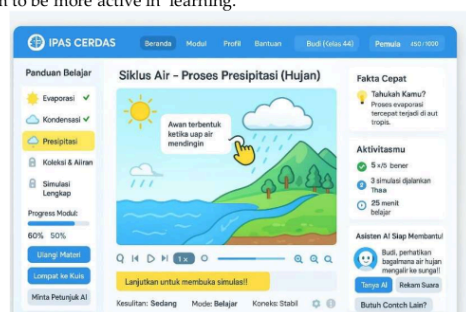


Figure 2. Deep Learning-Based Animated Media

Figure 2 shows a deep learning-based animated media package designed for interactive learning on the water cycle, particularly the precipitation (rainfall) process. The interface includes a step-by-step module menu (from evaporation to collection and runoff), along with visual animations that support understanding through illustrations of clouds and rain. It also provides simulation controls, allowing students to learn more independently. In addition, the media features a *Quick Facts* section, activity or progress tracking, and an AI assistant that can offer help or explanations when needed. As a result, the media is not only visually engaging but also supports learning that is more adaptive, well-guided, and motivating for active participation. The implementation of this media in classroom learning activities is shown in Figure 3.



Figure 3. Classroom Learning Activities Using Deep Learning-Based Animated Media

Figure 3 illustrates a classroom learning session in which students use laptops to access deep learning-based animated media on the water cycle topic. Students learn more independently through

the interactive interface (module menu and simulation controls) while following guidance, while the teacher monitors their work, provides support, and assists when needed. This arrangement helps create a more active learning process.

Discussion

The incorporation of deep learning–animated media in the elementary science teaching is significantly beneficial to students' science concept knowledge, at least in the Water Cycle module. The data show that both groups started from relatively comparable baseline levels (mean pretest: experimental = 52.35; control = 51.80), so the learning gains observed after instruction can be more confidently attributed to the different treatments. After media had been employed, the average posttest score of the experimental group was 82.75 and the control group was 68.45. The 14.30-point gap in posttest means, along with the experimental group's higher N-Gain (30.40 points) compared to the control group (16.65 points; a 13.75-point difference), indicates that the media helped students develop deeper conceptual understanding rather than simply recalling information. Pedagogically, visual animation and interactivity support students in building mental models of abstract processes (e.g., cloud formation, rainfall, and water flow), reducing misconceptions through dynamic representations that are visible and can be explored. In line with this, evidence from a network meta-analysis in science education suggests that interactive learning environments (such as augmented reality, mixed reality, and interactive digital games) generally have stronger potential to improve cognitive and affective outcomes than conventional teaching, highlighting the value of multisensory engagement and active participation in strengthening learning results (Koç & Kanadlı, 2025).

Beyond visual presentation, the media also demonstrates potential to address individual learning needs through a staged and adaptive learning design. Features such as the sequential module menu (from evaporation to collection and runoff), simulation controls, and *Quick Facts* allow students to regulate their learning pace, revisit sections they do not yet understand, and explore independently according to their own level of difficulty. From a personalized learning perspective, this emphasis on adaptivity aligns with recent systematic-review evidence showing that AI-based adaptive learning systems (including machine learning and deep learning) can adjust content in real time using students' profiles and learning-behavior data, enable dynamic content sequencing, and increase engagement and learner autonomy (Xaveria & Kristianingsih, 2025). At the implementation level, the presence of an AI assistant and progress monitoring also reflects key characteristics of AI-driven intelligent tutoring systems, which are designed to track progress, provide feedback, offer hints, and deliver personalized scaffolding—so learning support does not rely solely on direct teacher intervention (C. C. Lin et al., 2023). Students' positive perceptions (84% reporting the material was easier to understand; 80% feeling more motivated to learn actively) are also consistent with findings that animation-based or interactive video materials tend to sustain motivation without excessively increasing cognitive load, although interactivity still needs to be carefully designed to avoid adding extraneous cognitive load for some learners (Tugtekin & Dursun, 2022). Moreover, the media's effectiveness compared with conventional teaching is confirmed by the posttest hypothesis test (Mann–Whitney), which produced a significance value of 0.012 (< 0.05). This indicates a statistically significant difference between the two groups, meaning that deep learning–based animated media does more than enrich visual representations—it improves science concept understanding more effectively than predominantly conventional instruction by combining interactivity, feedback, and more personalized learning support (Halkiopoulos & Gkintoni, 2024; Shemshack & Spector, 2020).

These findings offer advantages over previous studies because they do not merely reaffirm the value of visual-interactive technology for engagement and motivation—as Annetta et al. (2024) showed that visual imagery through spatial computing can strengthen understanding and retention, particularly for science literacy and vocabulary, and as Kuznetcova et al. (2025) emphasized the role of interactivity in building psychological immersion—but also provide more direct empirical evidence on science concept understanding through a quasi-experimental design with a control-group comparison.

Unlike Kuznetcova et al.'s work, which focuses on design principles and implementation accessibility for immersive storytelling, this study strengthens the effectiveness claim through measurable quantitative indicators, including higher posttest means, higher N-Gain, and a significant Mann-Whitney result ($p = 0.012$), supported by student perception data on interest, ease of understanding, support for visualizing abstract concepts, and increased motivation. In addition, while Matovu et al. (2023) reported that learning outcomes in immersive virtual reality for science education tend to vary even when engagement improves, this study shows more consistent and significant cognitive gains. These outcomes can be explained by the combined support of science-process visualization, instructional interactivity, and deep learning-driven adaptive features such as staged modules, simulation controls, learning-progress monitoring, and an AI assistant. In this way, the present findings support and extend earlier literature: they confirm the role of technology in improving learning engagement, while also going beyond prior work by demonstrating stronger effects on conceptual understanding and by foregrounding personalization more explicitly.

The implications of this study suggest that deep learning-based animated media deserves serious consideration as an instructional innovation in elementary science, as it has been shown to improve science concept understanding more effectively than largely conventional teaching and to receive positive student responses in terms of interest, ease of comprehension, visualization of abstract concepts, and learning motivation. Practically, these results point to the need for schools and teachers to integrate interactive-adaptive media as a complement to instructional strategies for science topics that are process-based and difficult to visualize, while also supporting differentiated learning through simulation controls, staged modules, progress monitoring, and AI-assisted support. From a policy and school-management perspective, the findings also highlight the need for an enabling implementation ecosystem, including teacher training in digital pedagogy, adequate devices and access, and responsible AI-use guidelines (e.g., protecting learning data and ensuring transparency about how the system functions). Academically, this study opens opportunities for further research to examine the durability of effects (long-term retention), effectiveness across other science topics, and more detailed evaluation of the adaptivity components (the extent to which personalization truly occurs and which factors contribute most), so that media design can become more targeted and scalable for elementary school contexts.

4. CONCLUSION

This study concludes that integrating deep learning-based animated media has a positive and statistically significant effect on improving elementary students' understanding of science concepts in the Water Cycle unit. The research objectives—examining the media's effectiveness in strengthening conceptual understanding, presenting content visually, and supporting individual learning needs—were addressed through findings showing that the experimental group achieved higher learning gains than the control group, both in mean posttest scores and N-Gain, and that this difference was statistically significant. These results suggest that animation media is not just a device to make abstract ideas visible, but is a type of interactive learning material that invites the learner to become actively involved and, as a result, the student's conceptual understanding is strengthened. In addition, the generally positive student comments imply that the media made learning more interesting, facilitated students' understanding of the course content, and increased their motivation to learn. In the context of instruction, these benefits will translate into deep learning and potentially closing the achievement gaps with better tailored learning support. Future research is recommended to examine whether the impact of the media is sustained over time by assessing long-term retention of conceptual understanding, to extend its use to other science topics that are abstract or process-oriented, and to evaluate in greater detail the effectiveness of deep learning-based adaptive components—particularly how student interaction data are used to personalize learning pathways and feedback. Further studies should also involve larger and more diverse samples, and develop instruments that capture learning-process aspects (e.g., interaction patterns and metacognitive indicators) so the mechanisms through

which the media influences conceptual understanding can be explained more comprehensively. Ongoing media development should focus on refining adaptive features, improving the AI assistant as scaffolding support, and adjusting the design so it remains effective across schools with varying levels of infrastructure.

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