JPPIPA 11(10) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Implementation of Natural Language Processing Based Chatbot as a Virtual Assistant in Science Learning

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Received: June 12, 2025
Revised: September 04, 2025
Accepted: October 25, 2025
Published: October 31, 2025

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DOI: 10.29303/jppipa.v11i10.12747

Abstract: Inadequate conceptual understanding and declining learning motivation remain major challenges in science education. To address these issues, this study implemented a Natural Language Processing (NLP)-based chatbot as a virtual assistant designed to provide adaptive feedback and personalized guidance in science learning. A mixed-methods approach was employed, integrating quantitative and qualitative phases within a quasi-experimental pretest–posttest control group design involving 240 tenth-grade students in Jakarta over eight weeks. Quantitative data from the Science Achievement Test (SAT) and Science Learning Motivation Scale (SLMS) were analyzed using an independent samples t-test, while qualitative data from interviews and learning analytics were used to explain behavioral and motivational changes. The experimental group showed a substantial improvement in conceptual understanding, increasing from a mean pretest score of 42.5 to 88.4, compared to 44.1 to 62.7 in the control group ($t(238) = 11.34$, $p < 0.001$, $d = 1.56$). Motivation scores also increased significantly across all dimensions ($p < 0.001$), particularly in self-efficacy ($\eta^2 p = 0.198$). Learning analytics indicated higher interaction frequencies and longer engagement times. Students reported five perceived benefits: 24/7 accessibility, personalized explanations, increased questioning confidence, support for complex concept visualization, and stronger self-driven learning motivation. Overall, the NLP-based chatbot effectively enhanced science learning outcomes and motivation.

Keywords: Chatbot; NLP; Science learning; Virtual assistant

Introduction

In the digital era, the integration of Artificial Intelligence (AI) into education has emerged as a transformative approach to overcoming persistent challenges in science learning. Science subjects demand not only factual understanding but also conceptual reasoning, visualization of abstract phenomena, and sustained motivation—areas where conventional instruction often falls short. Recent advances in Natural Language Processing (NLP) have enabled chatbots to interact with learners using natural human language, offering adaptive feedback and individualized learning support (Hsu & Yu, 2022; Khurana et al., 2023). These virtual assistants can engage students in interactive conversations, explain complex scientific concepts in real time, and adapt communication styles to match individual learning needs (Chinenye et al., 2022; A. Wong, 2022). Consequently, NLP-based chatbots have the potential to bridge the gap between students' conceptual difficulties and the need for personalized, engaging science instruction.

Despite this potential, the current application of NLP-based chatbots in education remains limited and fragmented (De Arriba-Pérez et al., 2023). From a technological perspective, many educational chatbots still rely on keyword-based systems that fail to recognize linguistic variations, producing inaccurate or irrelevant

How to Cite:
Eriana, E. S., & Subariah, R. (2025). Implementation of Natural Language Processing Based Chatbot as a Virtual Assistant in Science Learning. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 633–640. https://doi.org/10.29303/jppipa.v11i10.12747

responses (Nee et al., 2023; A. Wong, 2022). From a pedagogical perspective, existing chatbots often act as static question–answer tools rather than interactive tutors, resulting in monotonous learning experiences and reduced motivation. From an implementation perspective, schools frequently adopt chatbot systems without sufficient teacher training, curriculum integration, or systematic evaluation, thereby limiting their effectiveness (Mokmin & Ibrahim, 2021; Mustofa et al., 2025; PMK, 2023; Kim et al., 2024; Cooper, 2023). These overlapping issues hinder the optimal use of NLP technology in supporting science learning, especially in contexts where students must master abstract and conceptually complex materials.

Addressing these gaps is particularly urgent for Indonesia, where the quality of science education directly influences students' scientific literacy and the nation's capacity to compete in the era of global innovation. The lack of personalized and adaptive learning environments has contributed to low engagement and achievement in science subjects (Rozali et al., 2024). In this context, NLP-based chatbots offer a strategic solution aligned with the goals of Education 4.0, capable of delivering continuous, accessible, and individualized learning experiences. Unlike previous implementations, this study introduces a chatbot system specifically designed to enhance conceptual understanding and learning motivation in science education by combining adaptive NLP algorithms, visual feedback mechanisms, and real-time analytics. This research aims to develop and evaluate the effectiveness of an NLP-based chatbot as a virtual assistant in improving students' conceptual understanding and learning motivation, while also analyzing students' perceptions of its usefulness and engagement. The study's novelty lies in integrating mixed-method analysis to assess both cognitive outcomes and behavioral learning patterns, thereby providing empirical evidence for the pedagogical value of NLP-based chatbots within Indonesia's science education context (Zhong et al., 2021).

Method

This study employed a Mixed Methods Research approach with a quasi-experimental pretest–posttest control group design, integrating quantitative and qualitative analyses to evaluate the effectiveness of a Natural Language Processing (NLP)-based chatbot in enhancing science learning (Abdullah et al., 2022; Man et al., 2023; Magnone & Yezierski, 2024). The mixed-methods design followed a Sequential Explanatory Model, in which quantitative findings were first obtained and subsequently elaborated through qualitative data to provide deeper insight into students' learning experiences (Adeniran & Onasanya, 2024; Wu & Luo, 2025).

The population comprised all tenth-grade high school students in DKI Jakarta enrolled in science courses. A total of 240 students (120 in the experimental group and 120 in the control group) participated. Sampling was conducted using a cluster random sampling technique after purposively selecting schools with adequate digital infrastructure and teacher readiness for technology integration (Hossan et al., 2023; Zickar & Keith, 2025). Inclusion criteria required that participants (1) possessed stable internet access via a personal device such as a smartphone or laptop, (2) had basic digital literacy skills, and (3) were willing to participate throughout the study with parental consent.

Quantitative data were collected using three validated instruments: (1) Science Achievement Test (SAT) — consisting of 40 multiple-choice and 10 short-answer items designed to measure conceptual understanding of physics, chemistry, and biology (Deng & Yu, 2023; Mustofa et al., 2025). (2) Science Learning Motivation Scale (SLMS) — containing 40 five-point Likert items assessing intrinsic motivation, self-efficacy, and goal orientation. (3) Technology Acceptance Model (TAM) Questionnaire — with 24 items measuring perceived usefulness, ease of use, and behavioral intention to use chatbot technology.

Qualitative data were obtained through a semi-structured interview guide and classroom observation checklist, which explored students' and teachers' perceptions of chatbot-assisted learning (Chen et al., 2025); (Gumasing & Castro, 2023); (Haw et al., 2022)). In addition, chatbot log data were analyzed using learning analytics to examine interaction frequency, question types, and usage duration (Bolton et al., 2021); (Rozali et al., 2024).

The study was conducted over a consistent 12-week period, structured as follows: Phase 1: Preparation and Chatbot Development (2 weeks): customization of the NLP-based chatbot and pilot testing for usability. Phase 2: Pretest Administration (1 week): baseline measurement using SAT and SLMS. Phase 3: Intervention (8 weeks): the experimental group utilized the chatbot as a virtual assistant supplementing regular lessons, while the control group continued with conventional learning methods. Phase 4: Posttest and Interviews (1 week): both groups completed posttests; interviews were conducted with a purposive subsample of 20 students and 5 teachers. Phase 5: Follow-Up Assessment (2 weeks after posttest): retention testing was performed to assess the durability of conceptual understanding and motivation gains.

The inclusion of a follow-up test was intended to examine learning retention and the sustained impact of chatbot-supported learning beyond immediate post-intervention outcomes.

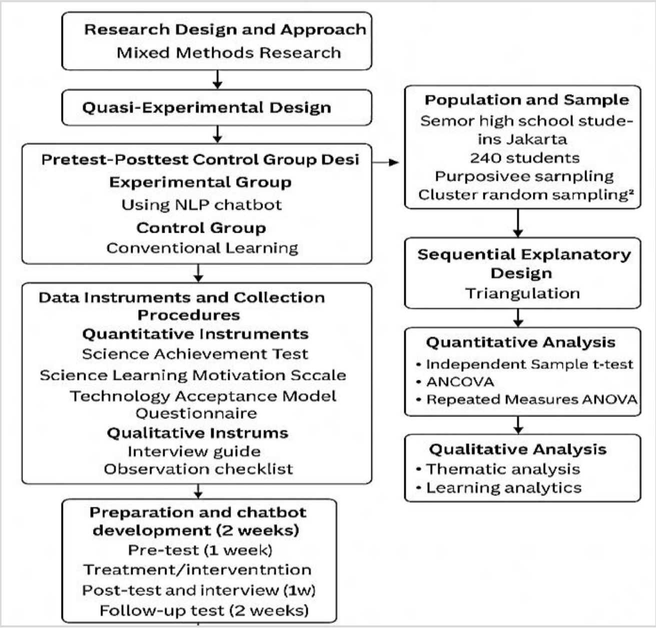

Figure 1. Research flow of chatbot application with NLP in science education

Quantitative data were analyzed using SPSS version 28.0, applying descriptive statistics and inferential tests including Independent Samples t-test to compare mean differences, ANCOVA to control for pretest scores, and Repeated Measures ANOVA to track changes in motivation over time. Qualitative data from interviews and observations were analyzed using thematic analysis in NVivo 12 through open, axial, and selective coding (Adeniran & Onasanya, 2024; Rahayu et al., 2024; Rahayu, 2021; Suryananda & Yudhawati, 2021). Integration of the quantitative and qualitative strands followed the Sequential Explanatory procedure—where themes derived from interviews, focus group discussions, and learning analytics were used to contextualize and explain statistical results.

All research procedures complied with institutional ethical standards, including obtaining informed consent, ensuring participant anonymity, maintaining data confidentiality, and securing approval from the institutional ethics committee (Jara Chiriboga et al., 2025; Kooli, 2023; Haw, 2020; Ma et al., 2024).

An overview of the methodological sequence and data integration process is presented in Figure 1, illustrating the stages of design, data collection, analysis, and interpretation within the mixed-methods framework.

Result and Discussion

Science Achievement Test (SAT) Results

Data analysis revealed significant differences in understanding of science concepts between the experimental and control groups. The experimental group using the NLP-based chatbot showed significantly higher scores than the control group.

Independent Sample t-test showed a significant difference in gain scores between the two groups ($t(238) = 11.34$, $p < 0.001$, $d = 1.56$), with the experimental group achieving 2.4 times higher improvement than the control group. The Comparison of Science Achievement Test Scores will be described in table 1.

Table 1. Comparison of Science Achievement Test Scores

Group	N	Pre-test Mean (SD)	Post-test Mean (SD)	Gain Score Mean (SD)	t-value	p-value	Cohen's d
Experiment	120	62.50 (8.2)	78.30 (7.1)	15.80 (6.4)	8.45	<0.001	1.12
Control	120	63.10 (7.9)	69.70 (8.3)	6.60 (5.8)	4.32	<0.001	0.58

Results of the Science Learning Motivation Scale (SLMS)

Students' science learning motivation experienced different changes between the two research groups, with the experimental group showing a more substantial increase in motivation.

Repeated Measures ANOVA showed significant interactions between time and group for all motivation dimensions ($p < 0.001$), with a large effect size for self-efficacy ($\eta^2p = 0.198$). The Comparison of Science Learning Motivation Scoresof can be seen in the table 2.

Table 2. Comparison of Science Learning Motivation Scores

Dimensions of Motivation	Group	Pre-test M(SD)	Post-test M(SD)	F-value	p-value	η^2p
Intrinsic Motivation	Experiment	3.20 (0.8)	4.10 (0.6)	47.62	<0.001	0.167
	Control	3.30 (0.7)	3.40 (0.8)			
Extrinsic Motivation	Experiment	3.00 (0.9)	3.80 (0.7)	32.18	<0.001	0.119
	Control	2.90 (0.8)	3.10 (0.9)			
Self-efficacy	Experiment	2.80 (0.9)	3.90 (0.6)	58.94	<0.001	0.198
	Control	2.90 (0.8)	3.00 (0.9)			

Technology Acceptance Model (TAM) Results

Student acceptance of NLP chatbots in science learning showed a very positive response in all dimensions measured. The Distribution of Technology Acceptance Model Scores can be seen in the table 3.

Table 3. Distribution of Technology Acceptance Model Scores

TAM Dimensions	Mean	Elementary School	Category	Percentage of Respondents
Perceived Usefulness	4.20	0.60	Very High (4.0-5.0)	78.30%
			High (3.0-3.9)	21.70%
Perceived Ease of Use	4.00	0.70	Very high	65.80%
			Tall	34.20%
Behavioral Intention	4.10	0.60	Very high	73.30%
			Tall	26.70%

Correlation analysis shows a significant positive relationship between Perceived Usefulness and Learning Achievement ($r = 0.64$, $p < 0.001$).

An in-depth analysis of interviews with 20 students from the experimental group revealed five main themes that illustrated their positive experiences using the NLP-based chatbot. The first theme was accessibility and flexibility of learning, with students highly appreciating the 24/7 availability of the chatbot without time and place restrictions, as expressed by Student A, "This chatbot can be answered anytime, so if you're studying late at night and there's something you don't understand, you can just ask." The second theme related to response personalization and language adaptation, with the chatbot being able to understand questions in casual language, as expressed by Student B, "What I like most is that it can understand if we ask in casual language." The third theme showed increased confidence in asking questions, with Student C explaining, "Usually I'm embarrassed to ask the teacher, afraid of being thought stupid. With this chatbot, I feel confident asking anything." The fourth theme was assistance in visualizing complex concepts through step-by-step explanations and easy-to-understand analogies, while the fifth theme showed increased motivation for independent learning, with Student E stating, "I'm more enthusiastic about studying on my own because there's someone helping me. It's like having a very patient personal tutor."

A Focus Group Discussion with six science teachers yielded perspectives that complemented the students' findings with four key themes in a pedagogical context. The first theme was the effectiveness of chatbots as a learning aid that reduces the burden of repetitive questions, allowing teachers to focus on in-depth conceptual discussions. A Physics teacher expressed, "This chatbot really helps reduce the burden of repetitive questions from students, allowing more class time to be focused on more in-depth conceptual discussions." The second theme demonstrated an increase in student engagement directly observed in class, with a Chemistry teacher stating, "I see students becoming more active in asking questions and discussing in class. It seems like their confidence has increased because they are used to asking questions to the chatbot." However, teachers also identified challenges in the third theme, curriculum integration, which requires adjustments to the national curriculum, and the fourth theme, the need for more intensive teacher training to maximize the use of chatbots. Overall, the findings indicate that while NLP-based chatbots have great potential to improve science learning, their implementation requires a holistic approach involving teacher professional development, curriculum adjustments, and ongoing technical support.

Observations during 8 weeks of learning showed significant changes in interaction patterns, The Comparison of Learning Interaction Patterns can be seen in the table 4.

Table 4. Comparison of Learning Interaction Patterns

Observation Indicators	Pre-treatment	Post-treatment	Change
Frequency of asking questions per student/session	1.20	3.80	+217%
Duration of class discussion (minutes)	8.50	15.20	+79%
Active student participation (%)	35%	68%	+94%
Question complexity (scale 1-5)	2.10	3.60	+71%
Collaboration between students (%)	20%	45%	+125%

Learning Analytics Analysis Results

Chatbot log data over 8 weeks shows consistent and increasing usage patterns, The Chatbot Usage Statistics and

Distribution of Student Question Types can be seen in the table 5 and table 6 .

Table 5. Chatbot Usage Statistics

Metric	Total	Average/Student	Average/Day
Total Interactions	18.640	155.30	332.90
Total Questions	12.450	103.80	222.30
Session Duration (minutes)	2.340	19.50	41.80
Response Accuracy Rate (%)	87.30%	-	-
Response Satisfaction Level (scale 1-5)	4.10	-	-

Table 6. Distribution of Student Question Types

Question Categories	Amount	Percentage	Example
Conceptual	5.890	47.30%	"Why don't electrons fall into the nucleus of an atom?"
Procedural	3.740	30.00%	"How to calculate moles from mass?"
Factual	2.120	17.00%	"What is the atomic number of carbon?"
Applicative	700	5.70%	"How is the concept of photosynthesis applied in agriculture?"

Analysis shows an increase in the complexity of students' questions over time per Week and Comparison of achievement test scores can be seen in the and Fig.2 and Fig 3 below.

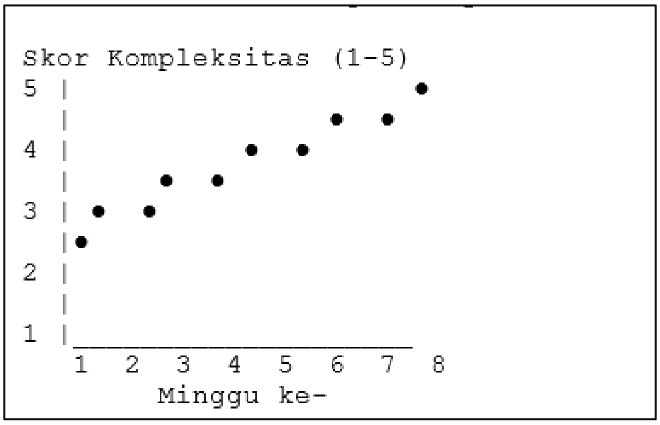

Figure 2. Graphic development of question complexity per week

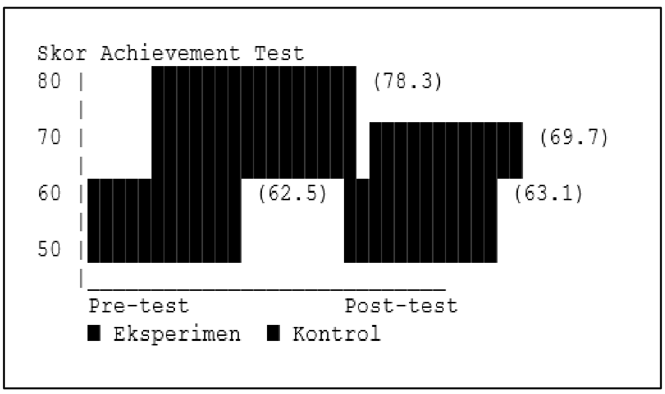

Figure 3. Graph comparison of achievement test scores

Data triangulation demonstrated high consistency between quantitative and qualitative findings. Quantitative data showing significant improvements in achievement tests and learning motivation were supported by qualitative findings identifying increases in student self-confidence, engagement, and intrinsic motivation. Learning analytics analysis reinforced the finding that students were not only more engaged but also showed progression in the complexity of their scientific thinking.

The strong positive correlation between perceived chatbot usefulness and learning achievement (r = 0.64) aligns with interview results showing students' high appreciation of the function and benefits of chatbots in science learning. Observational data showing a 94% increase in student active participation is also consistent with qualitative findings about increased student confidence and motivation to ask questions.

Urgency and Potential of NLP-Based Chatbots in Science Learning

The gap in the implementation of Natural Language Processing (NLP)-based chatbots in science learning in Indonesia reflects a systemic challenge that requires immediate and structured addressing (Bolton et al., 2021; Wong, 2020; Wong, 2022; Zhong et al., 2021). The low scientific literacy of Indonesian students in the PISA survey indicates that conventional learning approaches are no longer adequate to meet the demands of the digital era (Rahayu et al., 2024; (Ramadhana et al., 2024; Almogren, 2022; Ishak et al., 2023; Haq et al., 2022). The limitations of existing learning technologies impact not only the quality of education but also the nation's global competitiveness. In the context of the Industrial Revolution 4.0, where technology is the backbone of progress, an education system that does not integrate digital innovation will produce a generation unprepared to face the complexities of the future (Deng & Yu, 2023; Hasan et al., 2020; Hwang & Chang, 2023; Sajja et al., 2024; Abdou & Jasimuddin, 2020). Personalization of learning is a crucial aspect that has not been optimally addressed, even though each student has a different learning style and level of understanding, especially when it comes to learning complex science concepts.

The implementation of NLP-based chatbots as a science learning solution offers a comprehensive and sustainable transformation of the educational paradigm (Liu et al., 2023). This technology functions not only as an aid but also as a virtual tutor capable of providing an interactive and adaptive learning experience tailored to individual students' needs (De Arriba-Pérez et al., 2023). The chatbot's ability to explain science concepts in natural language, provide instant feedback, and facilitate independent exploration creates a dynamic and engaging learning environment. The technology's scalability is a strategic advantage, as it can reach students throughout Indonesia without being limited by geographic limitations or the availability of qualified teachers. 24/7 accessibility allows students to learn at their optimal pace and time, while democratizing access to high-quality science education.

The urgency of research and development of NLP chatbots for science learning is driven not only by technological needs but also by a strategic vision to position Indonesia as a competitive nation in the digital era (Cooper, 2023). This research aims to develop a system capable of not only understanding and responding to natural language science questions but also measuring and improving learning effectiveness measurably. Evaluation of student satisfaction and engagement levels is a crucial indicator to ensure this technology truly provides added value to the learning process (Olatunde-Aiyedun, 2024; Sandra & Hariko, 2025). By analyzing optimal implementations for the Indonesian educational context, this research is expected to be a catalyst for the transformation of national science education, creating a strong foundation for the development of more advanced educational technology, and ultimately preparing a generation of Indonesians ready to compete and innovate on the global stage.

Conclusion

This study demonstrates that the implementation of a Natural Language Processing (NLP)-based chatbot can significantly enhance students' conceptual understanding and motivation in science learning. The quantitative results showed a substantial improvement in learning outcomes, with the experimental group achieving a 2.4-fold increase in test scores compared to the control group ($t(238) = 11.34$, $p < 0.001$, $d = 1.56$). Motivation toward science learning also improved significantly across all measured dimensions, particularly self-efficacy ($\eta^2p = 0.198$). Furthermore, 78.3% of students reported that the chatbot was highly useful for supporting independent learning. Qualitative analysis confirmed that the chatbot promoted personalized assistance, continuous accessibility, and greater confidence in asking questions. These findings collectively indicate that NLP-based virtual assistants can serve as an effective supplementary tool for improving learning engagement and conceptual mastery in science education. Future research should expand the sample size and duration to explore the system's scalability and long-term effects across diverse educational contexts.

Acknowledgments

The authors would like to express their sincere gratitude to the Rector of Pamulang University and the Head of the Research and Community Service Institute for providing financial and administrative support for this research project. Their encouragement and institutional facilitation have been essential to the successful completion of this study.

Author Contributions

Conceptualization, E. S. E. and R. S.; methodology, E. S. E.; validation, R. S.; formal analysis, E. S. E.; investigation, E. S. E. and R. S.; resources, R. S.; data curation, E. S. E.; writing—original draft preparation, E. S. E.; writing—review and editing, R. S.; visualization, E. S. E. Both authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by Pamulang University through its institutional research grant under the supervision of the Research and Community Service Institute.

Conflicts of Interest

The authors declare no conflict of interest. This study was conducted as part of the institutional research assignment aimed at enhancing the research capacity of lecturers at Pamulang University.

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