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The Effect of PhET Interactive Simulation Media Based on the STEM Approach on Students' Learning Outcomes on Acid–Base Material in Grade XI Senior High School

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Abstract: The Effect of PhET Interactive Simulation Media Based on the STEM Approach on Students' Learning Outcomes on Acid–Base Material in Grade XI Senior High School. This study aims to determine the effect of PhET Interactive Simulation integrated with a STEM approach on students' learning outcomes and their improvement in acid–base material. This research employed a quasi-experimental method with a pretest–posttest control group design. The population consisted of all Grade XI MIPA students at SMA Negeri 4 Medan, with samples selected using purposive sampling, totaling 68 students divided into experimental and control classes. Data were collected through a learning outcomes test and analyzed using normality test, homogeneity test, independent sample t-test, and N-Gain analysis. The results showed that the average posttest score of the experimental class (85.06) was higher than that of the control class (77.88). The hypothesis test indicated that $p < 0.001$, meaning there is a significant effect on students' learning outcomes. Furthermore, the N-Gain value in the experimental class was 0.72 (high category), while the control class was 0.45 (medium category), indicating better learning outcomes improvement in the experimental class.

Keywords: acid–base, learning outcomes, PhET Interactive Simulation, STEM.

Abstrak: Pengaruh Media Phet Interactive Simulation Berbasis Pendekatan Stem Terhadap Hasil Belajar Siswa Pada Materi Asam Basa. *Penelitian ini bertujuan untuk mengetahui pengaruh penggunaan media PhET Interactive Simulation yang terintegrasi dengan pendekatan STEM terhadap hasil belajar siswa serta peningkatannya pada materi asam–basa. Penelitian ini menggunakan metode quasi eksperimen dengan desain pretest–posttest control group. Populasi penelitian adalah seluruh siswa kelas XI MIPA SMA Negeri 4 Medan, dengan sampel yang dipilih menggunakan teknik purposive sampling sebanyak 68 siswa yang dibagi ke dalam kelas eksperimen dan kelas kontrol. Data dikumpulkan melalui tes hasil belajar dan dianalisis menggunakan uji normalitas, uji homogenitas, uji t independent sample, serta analisis N-Gain. Hasil penelitian menunjukkan bahwa rata-rata nilai posttest kelas eksperimen (85,06) lebih tinggi dibandingkan kelas kontrol (77,88). Hasil uji hipotesis menunjukkan nilai p < 0,001, yang berarti terdapat pengaruh signifikan terhadap hasil belajar siswa. Selain itu, nilai N-Gain pada kelas eksperimen sebesar 0,72 (kategori tinggi), sedangkan pada kelas kontrol sebesar 0,45 (kategori sedang), yang menunjukkan bahwa peningkatan hasil belajar siswa lebih baik pada kelas eksperimen.*

Kata kunci: *asam basa, hasil belajar, PhET Interactive Simulation, STEM.*

INTRODUCTION

Education is a fundamental aspect of improving the quality of human resources, and science holds a strategic position as it shapes students' scientific thinking (Rahayu et al., 2022). Chemistry, as a branch of science, possesses unique characteristics by integrating conceptual understanding, symbolic representation, and practical laboratory experience. Therefore, mastering chemistry requires not only rote memorization but also the skill to connect concepts with everyday phenomena (Trianto, 2019). Nevertheless, various studies indicate that chemistry learning outcomes at the secondary school level remain low, particularly in topics perceived as complex. One such challenging subject is the concept of acids and bases, which demands a profound understanding of Arrhenius, Brønsted-Lowry, and Lewis theories, as well as proficiency in calculating pH, mastering titrations, and interpreting neutralization reactions. The complexity of acid-base chemistry often leads students to rely on memorizing formulas rather than achieving deep conceptual understanding (Nuraida et al., 2021). Furthermore, many teachers still rely predominantly on the lecture method for this topic (Maulika et al., 2019). Several studies have reported that students' understanding of acid–base concepts is still relatively low, particularly in abstract topics such as pH and ionization. For instance, previous research showed that more than 30% of students experience misconceptions in acid–base material, indicating the need for more interactive and visual learning media.

Previous research suggests that understanding acid-base solutions at the microscopic level is still categorized as merely "fair," indicating suboptimal classroom instruction. Educators are expected to pay closer attention to these results, as 32.89% of eleventh-grade science students still struggle to comprehend acid-base concepts at the microscopic level. Initial interviews with chemistry teachers at SMA Negeri 4 Medan reinforce this phenomenon, revealing that students often experience confusion when studying acids and bases, especially in linking theory to practical applications. While laboratory facilities are available to support practical work—which should be the primary means of strengthening conceptual understanding—implementation remains suboptimal due to limited instructional time and relatively large class sizes. Consequently, not all students have sufficient opportunity to engage actively in lab activities, leaving some acid-base concepts to be delivered theoretically. As a result, students' conceptual understanding has not fully developed, and the learning process lacks meaningful scientific experience (Mayer, 2009).

Therefore, an alternative learning approach is required to overcome these limitations, such as utilizing technology-based learning media like PhET Interactive Simulation (Situmorang, 2020). PhET is a computer-based simulation developed by the University of Colorado Boulder that presents various scientific phenomena virtually, allowing students to conduct interactive experiments that mimic a real laboratory (Taibu et al., 2021). This media assists students in understanding acid-base concepts through independent exploration, visual observation, and interactivity that stimulates curiosity. The primary advantage of PhET lies in its ability to visualize abstract concepts; for instance, in acid-base topics, students can observe changes in H^+ and OH^- ion concentrations, monitor virtual indicator color changes, and simulate titration processes (Haetami et al., 2023). This aligns with research showing that interactive simulations help students reduce misconceptions and more quickly understand the relationship between theory and real-world phenomena (Nuraida et al., 2021). The use of PhET can enhance scientific skills, motivation, and learning outcomes by providing students with the opportunity for independent conceptual exploration through virtual experiments (Taibu et al., 2021).

The integration of PhET Interactive Simulation with the STEM approach and STAD learning model is expected to create a more meaningful learning experience. PhET helps students visualize abstract chemical processes at the microscopic level, while the STEM approach connects concepts with real-world applications (Bybee, 2013). Meanwhile, the STAD model encourages collaboration and active participation among students. Therefore, the combination of these three components is considered relevant and complementary in improving students' learning outcomes (Saragih, 2021).

To ensure this media remains focused and relevant to 21st-century needs, an integrated approach encompassing Science, Technology, Engineering, and Mathematics (STEM) is necessary (Fitriyana et al., 2024). Implementing STEM in chemistry education requires an appropriate instructional model to ensure a systematic process, such as the Student Teams Achievement Divisions (STAD) type of Cooperative Learning (Slavin, 1994). Through the integration of the STEM approach and the STAD model, chemistry learning can become more active, meaningful, and student-centered (Amalia et al., 2025).

Based on the description above, it is evident that the problem of low student understanding in acid-base materials cannot be resolved solely through lectures or textbooks (Rutten et al., 2012). Innovative media like PhET Interactive Simulation, when combined with a STEM approach and implemented via the STAD cooperative learning model, offers a significant opportunity to provide learning that is more interactive, meaningful, and relevant to students in the digital era. Consequently, this study focuses on testing and analyzing the influence of STEM-based PhET Interactive Simulation media on student learning outcomes in acid-base concepts (Honey et al., 2014). However, previous studies have not specifically examined the integration of PhET simulation, STEM approach, and STAD model in acid–base learning at the senior high school level. Therefore, this study aims to fill this gap by investigating their combined effect on students' learning outcomes.

▪ METHOD

This research is a quasi-experimental study employing a pretest-posttest control group design (Sugiyono, 2019). The study was conducted at SMA Negeri 4 Medan during the even semester of the 2025/2026 academic year, from January to April 2026. The location was selected based on the school's technology implementation and the teachers' active involvement in instructional media innovation. The research population included all eleventh-grade MIPA (Mathematics and Natural Sciences) students across 11 classes, while the sample was selected using a purposive sampling technique. The samples were selected using purposive sampling with specific criteria, namely that both classes had relatively similar academic abilities, were taught by the same teacher, and had not previously been exposed to PhET Interactive Simulation in learning (Hake, 1999). This was intended to ensure the comparability between the experimental and control groups. The sample consisted of two classes with a total of 68 students: an experimental class utilizing PhET Interactive Simulation media within a STEM-based STAD (Student Teams Achievement Divisions) cooperative learning model, and a control class utilizing the STEM-based STAD model without PhET media (Wieman et al., 2008).

The research procedure was divided into three main stages: the preparation stage (preliminary study and instrument development), the implementation stage (administration of pretest, treatment, and posttest), and the final stage (data analysis and reporting) (Clark et al., 2016). The independent variable in this study is the use of PhET media, while the dependent variable is student learning outcomes in acid-base concepts.

The controlled variables include identical instructional time, the same teacher, the same learning materials, identical learning models and approaches, as well as the same pretest and posttest instruments. The data collection instrument consisted of a 40-item multiple-choice test that had been tested for validity, reliability, difficulty index, and discrimination power. In addition to the test, data were also collected through teacher interviews, learning outcome assessments, and supporting documentation such as attendance lists and activity photographs.

The instrument used in this study was validated before implementation. The validity test was conducted using content validity by expert judgment, while the reliability test was analyzed using Cronbach's Alpha. The results indicated that the instrument was valid and reliable for measuring students' learning outcomes. Data analysis techniques were performed to evaluate the instrument's quality and test the research hypotheses. Prerequisite analysis tests included the Shapiro-Wilk normality test and Levene's homogeneity test. Subsequently, hypothesis testing was conducted using an independent sample t-test to determine significant differences in learning outcomes between the two classes. To measure the magnitude of the improvement in student learning outcomes after the treatment, the researcher utilized the N-Gain (Normalized Gain) formula, which was then interpreted into low, medium, or high categories.

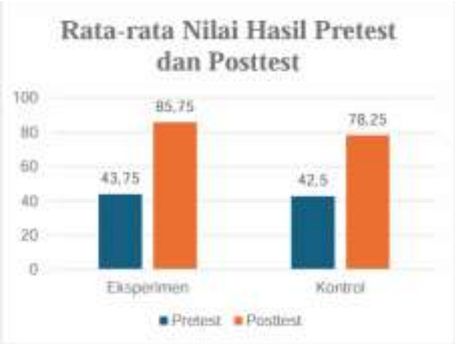
▪ RESULT AND DISCUSSION

The research conducted at SMA Negeri 4 Medan from January to February 2026—involving Class XI-4 as the experimental group and Class XI-3 as the control group, both taught using the STEM approach and the STAD-type Cooperative Learning model—demonstrated significant results in acid-base materials. Prior to the administration of the test instrument, expert validation and a trial run were conducted with students in Class XII-3. Out of the 40 initial test items, 25 were declared valid. The instrument's reliability test yielded a coefficient of 0.9134, which is categorized as very high. In the data analysis stage, the normality test results indicated that both pretest and posttest data for the experimental and control classes were normally distributed, with significance values greater than 0.05. Similarly, the homogeneity test confirmed that the variance between the data of the two classes was homogeneous.

Tabel 1. Independent Sample t-Test Results

Kelas	N	Mean	Std. Deviasi	t hitung	Sig. (2-tailed)	Keterangan
Eksperimen	34	85,06	6,773	4,826	0,000	Ha diterima
Kontrol	34	77,88	5,415			

The hypothesis testing using the independent sample t-test yielded a significance value (Sig. 2-tailed) of 0.000, which indicates that Ha is accepted. This proves that there is a significant influence of using STEM-based PhET Interactive Simulation media on student learning outcomes. Quantitatively, the average posttest score of the experimental class reached 85.06, which is notably higher than the control class average of 77.88.



Grafik 1. Analysis of Average Pretest and Posttest Scores

Based on the graph, it is evident that an increase in learning outcomes occurred in both classes; however, the experimental group showed a more significant improvement. This demonstrates that the use of STEM-based PhET Interactive Simulation media is capable of providing a superior learning experience for students.

Tabel 2. N-Gain Analysis Results

Kelas	Rata-rata Pretest	Rata-rata Posttest	Rata-rata N-Gain	Kategori
Eksperimen	41,94	85,06	0,75	Tinggi
Kontrol	41,06	77,88	0,62	Sedang

The improvement in understanding is further evidenced by the N-Gain test, where the experimental class achieved a score of 0.75 (high category), while the control class only reached 0.62 (medium category). These results indicate that the increase in student learning outcomes in the class utilizing PhET Interactive Simulation media was higher than in the class that did not use the media. This suggests that the use of PhET media not only influences the students' final learning outcomes but also significantly impacts the improvement of their conceptual understanding throughout the learning process.

The superior learning outcomes in the experimental class are attributed to the ability of PhET media to visualize abstract chemical concepts, such as making the interactions between H^+ and OH^- ions more concrete. Through these simulations, students can conduct independent virtual experiments, manipulate concentration variables, and observe phenomena directly, which fosters critical and constructivist thinking. The integration of the STEM approach adds further value by training students to solve problems systematically and relate chemical concepts to real-life applications.

The higher learning outcomes in the experimental class can be explained by the use of PhET Interactive Simulation, which allows students to visualize abstract concepts at the microscopic level. In acid–base material, concepts such as ionization and pH are difficult to observe directly, and PhET helps bridge this gap by providing interactive visual representations.

In addition to the media and approach, the use of the STAD-type cooperative learning model played a role in enhancing learning outcomes through heterogeneous group interaction and individual accountability. These findings are consistent with previous research stating that PhET simulations are effective in reducing misconceptions and making chemistry learning more interactive and engaging for students (Nuraida et al., 2021; Taibu et al., 2021). Overall, the combination of PhET media, the STEM approach, and the STAD model is proven to have a significant positive influence on students' academic achievement in acid-base materials.

▪ CONCLUSION

The use of PhET Interactive Simulation media, supported by the STEM approach and the STAD learning model, has a real and significant impact on student academic achievement in acid-base materials. This technological integration successfully creates a substantial difference in learning outcomes compared to conventional methods that rely solely on the STEM approach and the STAD model. Beyond improving final grades, this innovation effectively accelerates students' conceptual understanding, as evidenced by the "High" category of learning outcome improvement (N-Gain). This indicates that the visualization of abstract chemical phenomena through interactive simulations is a relevant educational solution for strengthening student engagement and enhancing the effectiveness of science teaching at the secondary school level.

This study has several limitations. First, the implementation of the learning process was conducted in a limited number of meetings, which may not optimally reflect the long-term impact of the treatment on students' learning outcomes. Second, the sample was limited to one school and selected using purposive sampling, which may limit the generalizability of the findings to a broader population. Third, the effectiveness of PhET Interactive Simulation is influenced by the availability of technological facilities such as computers and internet access, which may differ across educational settings. In addition, this study only focused on cognitive learning outcomes and did not measure other aspects such as students' attitudes or skills, which could provide a more comprehensive evaluation of the learning process.

Given the positive impact produced, teachers and prospective educators are strongly encouraged to begin integrating interactive simulation-based learning media, such as PhET, into teaching and learning activities—especially for chemistry topics characterized by microscopic concepts. Furthermore, schools should continue to promote the enhancement of teachers' skills in technology-based classroom management to ensure a more conducive learning process. For future researchers, this study could be expanded by exploring other factors influencing learning outcomes or applying this simulation media combination to a broader range of chemistry topics to obtain more comprehensive data for the advancement of science education.

▪ REFERENCES

Amalia, N. R., Marzal, J., & Kamid, K. (2025). The Effect of the Implementation of Learning Models Student Teams Achievement Division (Stad) Stem Based on Mathematical Critical Thinking Ability Reviewed from Mathematics Learning Styles. Enrichment: *Journal of Multidisciplinary Research and Development*, 2(10).

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. NSTA Press.

Clark, R. C., & Mayer, R. E. (2016). E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning (4th ed.). Wiley.

Fitriyana, N., Rahmawati, Y., & Nofiana, M. (2024). Integrated STEM learning to develop students' 4C skills in chemistry education. *Journal of Technology and Science Education*, 14(1), 45–56.

Haetami, A., Zulvita, N., Dahlan, Maysara, Marhadi, M. A., & Santoso, T. (2023). Investigation of Problem-Based Learning (PBL) on Physics Education Technology (PhET) Simulation in Improving Student Learning Outcomes in Acid-Base Material. *Jurnal Penelitian Pendidikan IPA*, 9(11), 9738–9748. https://doi.org/10.29303/jppipa.v9i11.4820.

Hake, R. R. (1999). Analyzing change/gain scores. Indiana University.

Honey, M., Pearson, G., & Schweingruber, H. (2014). STEM integration in K-12 education. National Academies Press.

Maulika, F., Kurniawan, R. A., & Kurniasih, D. (2019). Pengembangan Media Pembelajaran Indikator Asam Basa alami berbasis bioselulosa. *Ar-Razi Jurnal Ilmiah*, *7*(1), 56-64.

Mayer, R. E. (2009). Multimedia learning (2nd ed.). Cambridge University Press.

Nuraida, O., Akbar, G. S., Farida, I., & Rahmatullah, S. (2021). Using PhET simulation to learning the concept of acid-base. *Journal of Chemistry: Conference Series*, 6596/1869/1/012020.

Rahayu, R., Rosita, R., Rahayuningsih, Y. S., Hernawan, A. H., & Prihantini. (2022). Implementasi Kurikulum Merdeka Belajar Di Sekolah Penggerak. *Jurnal Basicedu*, 6(4), 6313–6319. https://doi.org/10.31004/jpion.v1i1.1

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. Computers & Education, 58(1), 136–153.

Saragih, S. (2021). The effect of learning models on student achievement in chemistry. Jurnal Pendidikan dan Pembelajaran Kimia, 10(1), 45–52.

Situmorang, M. (2020). The development of innovative chemistry learning materials. Jurnal Pendidikan dan Pembelajaran Kimia, 9(2), 123–130.

Slavin, R. E. (2015). *Cooperative Learning: Theory, Research, and Practice*. Boston: Allyn and Bacon.

Slavin, R. E. (1994). Student Teams–Achievement Divisions (STAD): *Cooperative learning method*. Englewood Cliffs, NJ: Prentice-Hall.

Sugiyono. (2019). *Metode penelitian kuantitatif, kualitatif, dan R&D*. Alfabeta.

Taibu, R., Mataka, L., & Shekoyan, V. (2021). Using PhET simulations to improve scientific skills and attitudes of community college students. *International Journal of Education in Mathematics, Science and Technology (IJEMST)*, 9(3), 353–370.

Trianto. 2019. *Mendesain Model Pembelajaran Inovatif, Progresif, dan Kontekstual*. Jakarta: Kencana.

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. Science, 322(5902), 682–683.