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The effect of gizmos virtual laboratory on scientific reasoning in biology education

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ABSTRACT

Scientific reasoning skills are fundamental in biology education, yet their development remains a challenge in conventional learning. Virtual laboratories like Gizmos offer a promising alternative to address this issue. Therefore, this study aimed to analyze the effect of the Gizmos virtual laboratory on seventh-grade students' scientific reasoning skills on the ecosystem topic. This study employed a one-group pretest-posttest design, with data collected through a scientific reasoning test and a student response questionnaire. The results showed a significant improvement in students' scientific reasoning skills ($p < 0.05$) with a moderate N-gain score. Furthermore, students demonstrated positive responses towards the virtual laboratory, although some technical challenges were reported. These findings suggest that the Gizmos virtual laboratory is an effective tool for enhancing scientific reasoning in biology education, with teacher guidance being crucial for optimal implementation.

INTRODUCTION

Scientific reasoning skills are crucial for enhancing science education and elevating analytical competencies among junior high school students (Drummond & Fischhoff, 2017; Luo et al., 2025). These skills encompass a range of scientific thinking abilities, including structured problem investigation, hypothesis formulation and testing, variable management, experimental result analysis, and the delivery of coherent and integrated explanations (Bao et al., 2009; Zeineddin & Abd-El-Khalick, 2010). Ideally, the science learning process affords students direct experiences in observation, investigation, and evidence-based conclusion drawing. This reliance on empirical data from experiments, observations, or modelling is vital for scientific reasoning development (Kind & Osborne, 2017). Moreover, cultivating scientific reasoning skills promotes data-informed thinking, enabling individuals to critically evaluate information, make rational decisions, and engage responsibly in public discourse (Lawson, 2004). Consequently, enhancing students' scientific reasoning skills aligns closely with the primary objectives of science education, which are to foster scientific thinking and prepare students to be engaged citizens within their communities (Orhan & Genç, 2024).

Creating an interactive, exploratory, and meaningful science learning process that engages students in authentic practices and sustains their interest remains a primary challenge in the field (Habig & Gupta, 2021; McComas, 2014). Observations conducted during PPL (Field Experience Practice) I revealed that science instruction often prioritizes conceptual understanding at the expense of sufficient exploration. Interviews with seventh-grade students indicated that they found the science curriculum unengaging due to limited variety in instructional methods. Seifert, (2004) notes that boredom in learning arises from minimal student participation and less engaging material, adversely impacting motivation. In response to these findings, I evaluated the learning design for the topic of ecosystems implemented by the mentor teacher for grade 7. The existing activity required students to observe local ecosystems and catalogue organisms. While this approach is valuable for initial exposure, it presents limitations in facilitating deeper student engagement, particularly in discovering complex organism relationships from concrete data. This limitation aligns with established pedagogical challenges, as core ecological concepts like population dynamics and environmental changes inherently require long observation periods to be fully understood (Fancovicová & Prokop, 2011; Markowitz et al., 2018). Therefore, integrating innovative, technology-based learning activities, such as virtual laboratories, becomes essential to allow students to explore these complex topics in an interactive and data-driven manner (Asare et al., 2023; Choo, 2021).

One of the innovative solutions is the implementation of Explore Learning Gizmos (Ecosystems - Middle School STEM Case), an interactive virtual laboratory that simulates the role of a scientist in managing ecosystem balance. This virtual laboratory empowers students to manipulate variables, observe population changes, and test hypotheses within a dynamic digital environment. The use of Gizmos not only clarifies ecosystem concepts but also provides valuable experience in addressing data-based challenges, thereby supporting the development of scientific reasoning skills. Extensive research on Gizmos as a virtual laboratory tool in science education has yielded positive results regarding conceptual understanding, student engagement, and enhanced scientific reasoning skills. For instance, a study by Dela Cruz & Hermosura, (2024) demonstrated that integrating Gizmos into ninth-grade science instruction significantly improved student attitudes, engagement, interest, and motivation, particularly among female students who exhibited favourable perceptions of digital simulation-based learning. Another investigation by Gnesdilow et al., (2016) comparing physical and virtual laboratories revealed that students who utilized virtual laboratories experienced greater advancements in conceptual understanding and were more engaged in conceptual discussions, fostering deeper scientific reasoning. These specific findings are encapsulated by the broader principle established by Davenport & Quellmalz, (2017), who argue that interactive simulations provide a more valid means of assessing complex scientific inquiry and reasoning skills such as those needed to model dynamic ecosystems than traditional methods that often fail to capture these higher-order skills.

This study aims to evaluate the effectiveness of implementing Explore Learning Gizmos (Ecosystems - Middle School STEM Case) in enhancing the scientific reasoning skills of seventh-grade junior high school students and to analyze student feedback regarding the media's integration into the science curriculum. The anticipated results will provide valuable insights into the potential of digital simulation tools to enhance science education quality and contribute to the progression of innovative, technology-based learning models. Thus, this research could serve as a reference for educators and researchers in developing more effective, engaging, and meaningful science teaching strategies for students.

METHODS

Research Design

This study employed a quantitative approach using a pre-experimental one-group pretest-posttest design. It was conducted at a public junior high school (SMP) in Malang City during March–April 2025. The study involved only one group of students without a control group (Creswell & Creswell, 2018). Before the treatment, students were given a pre-test to assess their initial scientific reasoning skills. The treatment involved instruction using the Explore Learning Gizmos virtual laboratory, followed by a post-test to measure improvement. This design allows the researcher to observe any difference in scores before and after the treatment. The research design is shown in Table 1.

Table 1.
Research Design

Group	Pre-test	Treatment	Post-test
Experiment	O	X	O

(Creswell & Creswell, 2018)

Population and Samples

The population of this study consisted of seventh-grade students at SMP Negeri 2 Malang. A sample of one class, comprising 33 students, was selected using a purposive sampling technique. The demographic characteristics of the research sample are presented in Table 2.

Table 2.
Demographic Characteristics of the Research Sample

Characteristic	Description
School	SMP Negeri 2 Malang
Grade level	Seventh grade
Number of Students (n)	33
Sampling Technique	Purposive sampling

Instrument

The independent variable in this study is the instructional media used, specifically the Explore Learning Gizmos virtual laboratory during the ecosystem learning process. The dependent variable is students' scientific reasoning skills, measured using an instrument consisting of eight questions in a combination of multiple-choice and open-ended formats. The instrument was developed based on three core aspects of scientific reasoning: analysis, evaluation, and creativity (Yanto et al., 2019). The indicators of each aspect are presented in Table 3.

Table 3.
Indicators of Scientific Reasoning Skills

Aspect	Indicators	Item Number
Analyze	Distinguishing relevant sections of factual objects	1
	Analyzing relationships between variables	2
	Describing the causal relationship of a phenomenon	3
Evaluate	Reviewing factual statements critically	4
	Testing the validity of the procedure based on data collection	5
Create	Designing scientific procedures	6
	Formulating hypothesis	7
	Formulating a conclusion	8

(Yanto et al., 2019)

Research instruments, including the pre-test, post-test, and student response questionnaire, were validated by a science teacher and deemed valid in terms of content.

Procedure

The procedure began with obtaining permission to conduct the research at the school, followed by preparation of lesson plans and instruments including pre-test, post-test, and student response questionnaires. In the first session, a pre-test was administered to assess students' initial scientific reasoning skills. Then, the treatment was given in the form of learning using the Explore Learning Gizmos virtual laboratory. In the second session, students were given a post-test and asked to fill out the response questionnaire. Students accessed the virtual laboratory via their own smartphones. The research procedure is illustrated in Figure 1.

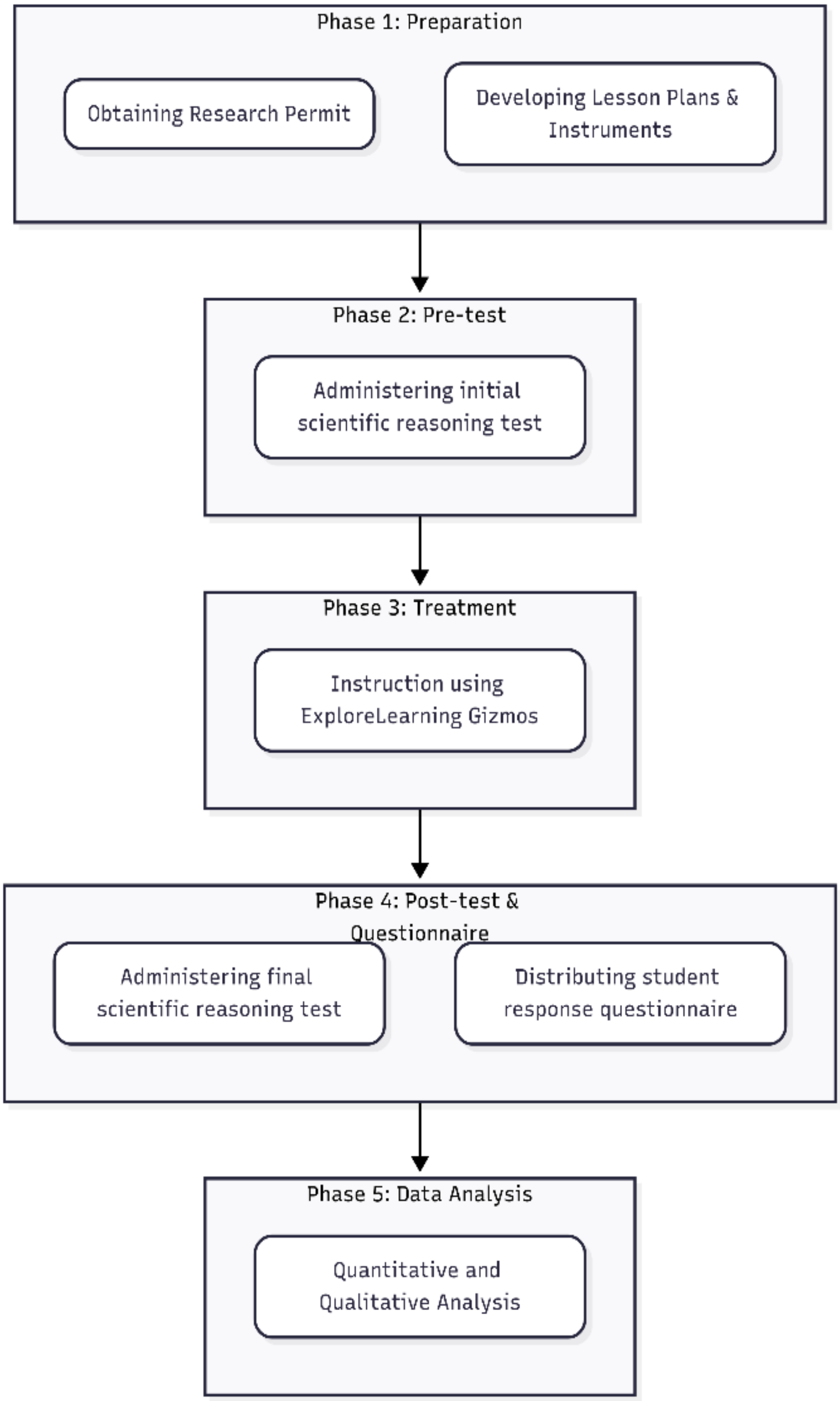

Figure 1. Research Procedure Flowchart

Data Analysis Techniques

Pre-test and post-test data were analyzed quantitatively to test the effectiveness of the treatment on students' scientific reasoning skills. Data processing and interpretation were carried out using SPSS software to determine whether there was a statistically significant difference between pre-test and post-test scores after using the Explore Learning Gizmos virtual laboratory. The hypotheses tested in this study are as follows:

H_0 : There is no significant difference between students' pre-test and post-test scores in scientific reasoning skills after the treatment

H_a : There is a significant difference between students' pre-test and post-test scores in scientific reasoning skills after the treatment

Responses to the closed-ended questions were averaged per item and categorized using a Likert scale as presented in Table 4.

Table 4.
Likert Scale Categories

Average Score	Category
1,00 – 1,79	Strongly disagree
1,80 – 2,59	Disagree
2,60 – 3,39	Neutral
3,40 – 4,19	Agree
4,20 – 5,00	Strongly agree

(Likert, 1932)

Meanwhile, data from the open-ended questions in the student response questionnaire were analyzed using a qualitative content analysis approach. This aimed to explore students' experiences and difficulties in using the Explore Learning Gizmos virtual laboratory in the ecosystem topic. Students' responses were analyzed to derive valid and replicable insights into the learning context they experienced (Krippendorff, 2018). The normalized gain of averages (N-gain) was also calculated to determine the improvement in scientific reasoning skills. (Hake, 1998) defines the average N-gain as follows:

$$\langle g \rangle = \frac{\langle post\ test \rangle - \langle pre\ test \rangle}{100 - \langle pre\ test \rangle}$$

Where the brackets ⟨ ⟩ indicate the average score, and the value of 100 may be replaced by the maximum score of the test used. The interpretation of ⟨g⟩ is classified as shown in Table 5.

Table 5.
Interpretation of ⟨g⟩ Scores

$\langle g \rangle$	Category
$\langle g \rangle \geq 0.7$	High
$0.7 > \langle g \rangle \geq 0.3$	Medium
$\langle g \rangle < 0.3$	Low

RESULTS AND DISCUSSION

Effectiveness of the Virtual Laboratory Media on Students' Scientific Reasoning Skills

The effectiveness of using the Explore Learning Gizmos virtual laboratory (Ecosystems STEM Case) on students' scientific reasoning skills was analyzed based on the differences between students' pre-test and post-test results. These differences were examined through hypothesis testing using the Wilcoxon Signed Rank Test, as the data did not follow a normal distribution, according to the results of a prior normality test. The results of the hypothesis test and other relevant calculations are presented in Table 6.

Table 6.
Results of Hypothesis Test and N-Gain Calculation

Statistical results	Pre-test	Post-test
N	33.00	33.00
Mean	53.76	74.73

Statistical results	Pre-test	Post-test
Median	57.00	78.00
Standard deviation	14.11	7.94
Minimum	30.00	55.00
Maximum	75.00	90.00
N-Gain	–	0.45
N-Gain category	–	Medium
Z	–	– 5.02
p	–	0.000

Based on the analysis, there was an observable increase in the average score from the pre-test to the post-test. This improvement is further supported by the significance test, which yielded a p-value < 0.05, indicating a statistically significant difference between pre-test and post-test scores. Additionally, the N-gain calculation falls within the "medium" category.

Overall, this study demonstrates that the Explore Learning Gizmos virtual laboratory effectively enhances students' scientific reasoning skills. Skills such as analyzing relationships between variables, formulating hypotheses, and designing scientific procedures were facilitated through the exploratory and visual experiences provided by the Explore Learning Gizmos (Ecosystems STEM Case) platform. This finding is consistent with the studies by Meister & Upmeier zu Belzen, (2021) and Chen et al., (2019), which emphasize that virtual experiments and simulation technologies can create safe and repeatable learning environments for testing hypotheses, manipulating variables, and constructing data-driven scientific arguments. From a constructivist learning perspective, the ability to safely manipulate variables and receive immediate feedback allows students to actively build their own understanding of complex ecological relationships, a process that is difficult to replicate in traditional settings (Reyes et al., 2024). Thus, the use of virtual laboratories not only enriches the learning experience but also supports students' engagement in deeper and more structured scientific reasoning processes (Shofiyah et al., 2025).

Further analysis was conducted on each indicator of scientific reasoning skills, comparing the average pre-test and post-test scores across eight indicators grouped into three core aspects: analysis, evaluation, and creativity. The differences in average scores for each indicator are illustrated in Figure 2.

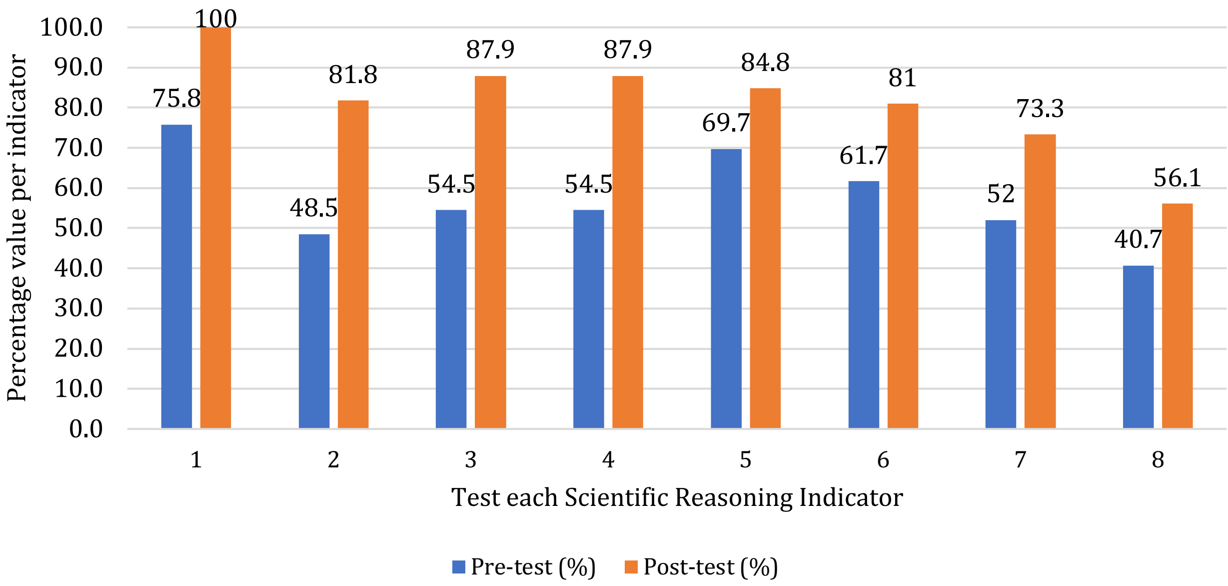

Figure 2. Average percentage of value for each scientific reasoning indicator

The figure above illustrates the differences in scores across each scientific reasoning indicator, where the x-axis (labelled 1–8) represents the items listed in Table 3. An overall improvement is evident across all indicators following the treatment. The most substantial increases occurred in indicator no. 3 explaining cause-and-effect relationships and indicator no. 4 evaluating factual statements. The smallest improvement was found in indicator no. 5, testing the validity of data collection procedures. However, in terms of absolute score values, indicator no. 1, distinguishing key parts of information, achieved the highest scores in both the pre-test and post-test, whereas indicator no. 8, designing scientific procedures consistently, received the lowest scores.

The data suggest that students made significant gains in their ability to explain cause-and-effect relationships, a skill effectively supported by the Explore Learning Gizmos virtual laboratory. For instance, when students were prompted to choose between testing the impact of adding wolves or bees to an ecosystem, they had to predict the consequences for other species and infer the broader ecological effects based on previously analyzed data. This finding aligns with Zhou et al., (2016), who reported that students' ability to analyze causal relationships between variables improves when experimental data are provided.

The creating aspect, specifically designing scientific procedures, received the lowest scores on both assessments. Taken together, the pronounced improvement in explaining causal relationships compared with the minimal gain in designing procedures provides a nuanced insight into the pedagogical impact of the guided inquiry model used in this study. According to Arzu, (2014), students engaged in guided inquiry typically have limited opportunities to independently design investigations; however, such guided experiences can serve as a foundation for transitioning to open inquiry, where students are expected to develop and formulate their own investigative procedures.

Further discussion of the learning activities and implementation of the Explore Learning Gizmos virtual laboratory (Ecosystems Case) reveals that science instruction on the ecosystem topic was designed to actively engage students in scientific inquiry. The learning model applied was guided inquiry, whose full instructional syntax was integrated into the Gizmos virtual lab simulation from problem orientation, hypothesis formulation, and hypothesis testing to data conclusion. The activities were conducted over two sessions: the first included the pre-test and implementation of the treatment, and the second comprised the post-test, reflection, and filling of the student response questionnaire. Students accessed the virtual laboratory using their own smartphones.

The Explore Learning Gizmos (Ecosystem STEM Case) was delivered through an interactive, case-based scenario, in which students took on the role of park rangers at Atlas National Park, tasked with restoring a disrupted ecosystem. They collected species population data, analyzed changes, formulated hypotheses, ran simulations involving species reintroduction, and drew conclusions based on virtual experimental results. Each stage of the activity directly elicited indicators of scientific reasoning skills, such as identifying key information, analyzing variable relationships, explaining cause-and-effect patterns, evaluating data, formulating hypotheses and conclusions, and designing scientific procedures. This media platform facilitates the development of all scientific reasoning indicators through engaging, data-driven, and inquiry-based activities grounded in scientific methods.

In addition to assessing the effectiveness of the Explore Learning Gizmos virtual laboratory (Ecosystem STEM Case) in improving students' scientific reasoning skills, it is also essential to evaluate students' responses to the learning activities. Student responses provide insight into the extent to which they felt supported, engaged, and interested in this technology-based learning process. The student response questionnaire was administered via Google Forms, containing both closed-ended and open-ended questions, and analyzed using the Likert scale categories. The results of the questionnaire analysis are presented in Table 7.

Table 7.
Results of Student Response Questionnaire Analysis

Item	**x̄**	**Category**
Enjoyment after the lesson	3.94	Agree
Understanding of the material	3.73	Agree
Interest/motivation to learn	4.12	Agree
Ability to complete tasks	3.45	Agree
Teacher support in understanding task	3.97	Agree

The average score for each item indicates that students responded positively to the implementation of the Explore Learning Gizmos (Ecosystem STEM Case) virtual laboratory as a learning medium. These findings suggest that students felt more engaged, interested, and supported in understanding the content, and more confident in completing tasks even though the simulation was in English with guidance and translations provided by the teacher. This aligns with findings by Dela Cruz

& Hermosura, (2024), who concluded that the use of Gizmos digital simulations positively influences students' attitudes toward science learning in terms of engagement, understanding, motivation, and overall perception of the learning process. Therefore, implementing interactive simulation-based virtual laboratories like Gizmos can be an effective strategy to enhance the quality of science education. The results of students' open-ended responses are summarized in Table 8.

Table 8.
Most Frequently Occurring Words

Word	Item 1	Item 2	Item 3
Fun	10	2	4
Interesting	8	3	7
Exciting	8	0	5
Internet	2	10	6
Language	2	7	7
English	0	7	2
Clear	8	2	2
Images	8	2	2
Indonesian	2	6	8
Graphics	2	6	2
Bugs	0	8	8

The open-ended questions asked students what they liked most about learning with the Gizmos virtual laboratory (item 1), what challenges they faced (item 2), and what suggestions they had for improving this type of learning (item 3).

Based on the table, it can be concluded that the use of the Explore Learning Gizmos (Ecosystem STEM Case) virtual laboratory received very positive responses from students. They found the learning process to be more interesting, interactive, and enjoyable. Students appreciated the appealing visuals such as images and animations, as well as the simulation flow that resembled a game, which made the content easier to understand and less monotonous. The simulation also sparked curiosity and challenged them to think critically when solving ecosystem-related scenarios. This is in line with McDonald, (2016), who stated that virtual simulations can simplify scientific processes into interactive models that enable students to explore variables independently or collaboratively, while also providing immediate feedback on their actions. Furthermore, virtual laboratories like Gizmos create a safe learning environment that supports cognitive development through visual interaction.

Nevertheless, some students reported technical challenges, such as unstable internet connections, limited device capabilities, or language barriers due to the content being in English. Similar issues have been widely reported in studies on the implementation of virtual laboratories, such as those reviewed by Deriba et al., (2024), who identified major challenges including limited access to devices and internet infrastructure, interface incompatibility, and insufficient technical training for teachers and students. However, these challenges were largely technical in nature and did not significantly diminish student enthusiasm for the learning activities. In fact, some students were able to overcome these issues using translation features or with teacher support. Crucially, the positive student responses should not be viewed in isolation from the cognitive gains documented earlier. The students' perception of the learning process as "fun," "interesting," and "exciting" likely translates into increased student engagement and motivation. This heightened affective state can lead to greater cognitive investment and persistence in problem-solving within the simulation (Gegenfurtner et al., 2021). Therefore, the engaging, game-like design of the Gizmos platform appears to be a key mediating factor that facilitates the development of scientific reasoning skills, creating an environment where students are not only able but also willing to engage in deeper cognitive processing.

Students' suggestions for improvement reflect their enthusiasm for continuing to learn through virtual laboratories. They expressed a desire for simulations to be offered in the Indonesian language for easier comprehension and recommended the use of school computers to avoid disparities in personal device specifications. With minor improvements and adequate technical support, digital simulation-based learning tools such as virtual laboratories hold great potential to be further developed as an effective and enjoyable method for promoting contextual and meaningful understanding of science content.

CONCLUSION

This study demonstrates that the implementation of the Explore Learning Gizmos virtual laboratory has the potential to enrich the science learning process by providing interactive experiences that encourage students to think scientifically and explore actively. Although there is still room for improvement, such as providing adequate devices and adapting instructional language these findings indicate that virtual laboratories can serve as an effective alternative for supporting the development of scientific reasoning among junior high school students. Moreover, students generally perceived the Gizmos experience as enjoyable and motivating, fostering greater engagement in the learning process. This series of positive responses reflects students' readiness to embrace technology-based learning methods, while also underscoring the importance of teacher support in the form of clear guidance and appropriate supervision to ensure that this potential is fully realized in everyday classroom practice.

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REFERENCES

Arzu, A. (2014). Transition between Open and Guided Inquiry Instruction. *Procedia - Social and Behavioral Sciences*, *141*, 407–412. https://doi.org/10.1016/j.sbspro.2014.05.071

Asare, S., Amoako, S. K., Biilah, D. K., & Apraku, T. B. (2023). The use of virtual labs in science education: A comparative study of traditional labs and virtual environments. *International Journal of Science Academic Research*, *04*(11), 6563–6569. https://www.scienceijsar.com/sites/default/files/article-pdf/IJSAR-1860.pdf

Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J., Liu, Q., Ding, L., Cui, L., Luo, Y., Wang, Y., Li, L., & Wu, N. (2009). Learning and scientific reasoning. *Science*, *323*(5914), 586–587. https://doi.org/10.1126/science.1167740

Chen, Y. C., Lu, Y. L., & Lien, C. J. (2019). Learning environments with different levels of technological engagement: a comparison of game-based, video-based, and traditional instruction on students' learning. *Interactive Learning Environments*, *29*(8), 1363–1379. https://doi.org/10.1080/10494820.2019.1628781

Choo, W. S. (2021). Student perspectives of various learning approaches used in an undergraduate food science and technology subject. *Journal of Food Science Education*, *20*, 146–154. https://doi.org/10.1111/1541-4329.12237

Creswell, W. J., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative adn Mixed Methods Approaches* (Fifth, Vol. 53, Issue 9). Sage Publications Inc.

Davenport, J. L., & Quellmalz, E. S. (2017). Assessing Science Inquiry and Reasoning Using Dynamic Visualizations and Interactive Simulations. In R. Lowe & R. Ploetzner (Eds.), *Learning from Dynamic Visualization*. Springer, Cham. https://doi.org/10.1007/978-3-319-56204-9_9

Dela Cruz, J. S., & Hermosura, J. P. C. R. (2024). The influence of Gizmos digital simulation on the perceptions of grade 9 high school learner. *Psychology and Education: A Multidisciplinary Journal*, *19*(4), 495–505. https://doi.org/10.5281/zenodo.11094161

Deriba, F. G., Saqr, M., & Tukiainen, M. (2024). Assessment of accessibility in virtual laboratories: a systematic review. *Frontiers in Education*, *9*. https://doi.org/10.3389/feduc.2024.1351711

Drummond, C., & Fischhoff, B. (2017). Individuals with greater science literacy and education have more polarized beliefs on controversial science topics. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(36), 9587–9592. https://doi.org/10.1073/pnas.1704882114

Fancovicová, J., & Prokop, P. (2011). Plants Have a Chance: Outdoor Educational Programmes Alter Students' Knowledge and Attitudes towards Plants. *Environmental Education Research*, *17*, 537–

551. https://doi.org/10.1080/13504622.2010.545874
Gegenfurtner, A., Narciss, S., Fryer, L. K., Järvelä, S., & Harackiewicz, J. M. (2021). Editorial: Affective Learning in Digital Education. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.630966
Gnesdilow, D., Fathema, N., Lin, F., Kang, S., Dornfeld, C., & Puntambekar, S. (2016). Exploring middle school students' science learning and discourse in physical and virtual labs. *Proceedings of the International Conference of the Learning Sciences (ICLS)*, 950–953. https://repository.isls.org/handle/1/351
Habig, B., & Gupta, P. (2021). Authentic STEM research, practices of science, and interest development in an informal science education program. *International Journal of STEM Education*, *8*(1). https://doi.org/10.1186/s40594-021-00314-y
Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809
Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education? *Science Education*, *101*(1), 8–31. https://doi.org/10.1002/sce.21251
Krippendorff, K. (2018). *Content Analysis: An Introduction to Its Methodology* (2nd ed.). Sage Publications.
Lawson, A. E. (2004). The nature and development of scientific reasoning: A synthetic view. *International Journal of Science and Mathematics Education*, *2*(3), 307–338. https://doi.org/10.1007/s10763-004-3224-2
Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, *22*(140), 55. https://legacy.voteview.com/pdf/Likert_1932.pdf
Luo, M., Sun, D., Zhu, G., Zhu, L., & Jia, F. (2025). Factors influencing scientific reasoning ability in junior secondary students: Examining gender and grade-level predictive differences. *Thinking Skills and Creativity*, *57*, 101824. https://doi.org/10.1016/j.tsc.2025.101824
Markowitz, D. M., Laha, R., Perone, B. P., Pea, R. D., & Bailenson, J. N. (2018). Immersive Virtual Reality field trips facilitate learning about climate change. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.02364
McComas, W. F. (2014). Nature of Science in the Science Curriculum and in Teacher Education Programs in the United States. In M. R. Matthews (Ed.), *International Handbook of Research in History, Philosophy and Science Teaching* (pp. 1993–2023). Springer Netherlands. https://doi.org/10.1007/978-94-007-7654-8_61
McDonald, C. V. (2016). STEM education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International*, *27*(4), 530–569. https://www.icaseonline.net/sei/december2016/p4.pdf
Meister, S., & Upmeier zu Belzen, A. (2021). Analysis of Data-Based Scientific Reasoning from a Product-Based and a Process-Based Perspective. *Education Sciences*, *11*(10), 639. https://doi.org/10.3390/educsci11100639
Orhan, U., & Genç, M. (2024). Socio-scientific reasoning of science, social studies and primary teachers. *Research in Science & Technological Education*. https://doi.org/10.1080/02635143.2024.2338808
Reyes, R. L., Isleta, K. P., Regala, J. D., & Bialba, D. M. R. (2024). Enhancing experiential science learning with virtual labs: A narrative account of merits, challenges, and implementation strategies. *Journal of Computer Assisted Learning*, *40*(6). https://doi.org/10.1111/jcal.13061
Seifert, T. (2004). Understanding student motivation. *Educational Research*, *46*(2), 137–149. https://doi.org/10.1080/0013188042000222421
Shofiyah, N., Jatmiko, B., Suprapto, N., Prahani, B. K., & Anggraeni, D. M. (2025). The use of technology to scientific reasoning in science education: A bibliometric and content analysis of research papers. *Social Sciences & Humanities Open*, *11*, 101534. https://doi.org/10.1016/j.ssaho.2025.101534
Yanto, B. E., Subali, B., & Suyanto, S. (2019). Improving students' scientific reasoning skills through the three levels of inquiry. *International Journal of Instruction*, *12*(4), 689–704. https://doi.org/10.29333/iji.2019.12444a
Zeineddin, A., & Abd-El-Khalick, F. (2010). Scientific reasoning and epistemological commitments: Coordination of theory and evidence among college science students. *Journal of Research in Science Teaching*, *47*(9), 1064–1093. https://doi.org/10.1002/tea.20382

Zhou, S., Han, J., Koenig, K., Raplinger, A., Pi, Y., Li, D., Xiao, H., Fu, Z., & Bao, L. (2016). Assessment of Scientific Reasoning: the Effects of Task Context, Data, and Design on Student Reasoning in Control of Variables. *Thinking Skills and Creativity*, *19*, 175–187. https://doi.org/10.1016/j.tsc.2015.11.004