ETDC Indonesian Journal of Research and Educational Review
Volume 5, No. 1, 2025, pp 838 - 847
e–ISSN 2809-3682
p–ISSN 2809-7505

https://doi.org/10.51574/ijrer.v5i1.4701

Bio-Math Synergy: Creating Relevant Cross-Disciplinary Learning in the Digital Age

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Article Info

Article history:

Received November 02, 2025
Accepted December 25, 2025
Published December 27, 2025

Keywords:

Bio-Math Synergy;
Digital Simulation;
High School Students;
Interdisciplinary Learning;
Numeracy Literacy.

ABSTRACT

High school learning is generally divided into isolated subjects, with biology deemed rote learning and math as formulas with no practical value. In the data-driven digital age, high school students find it difficult to connect statistical or algebraic concepts to biological events like the spread of viruses and changes in ecosystems. Lack of connection between these fields reduces computational thinking and scientific literacy. This study examines whether the "Bio-Math Synergy" learning model improves high school students' transdisciplinary comprehension. The study used computerized techniques to incorporate ecology, genetics, function modeling, and basic statistics. This quasi-experimental study used pretest-posttest control groups. Eleventh graders from two Wajo Regency high schools studied. The experimental class utilized the "Bio-Math Synergy" model to analyze biology lab data through an interactive simulation platform and spreadsheets, while the control class employed traditional learning methods. The findings indicated the experimental class had much higher numeracy literacy results than the control class. Students learn that biology requires mathematics by modeling bacterial development and Mendel's rules digitally. Because STEM education felt more relevant to contemporary technology, an interest poll showed a 40% rise in student excitement for STEM jobs. This article provides a practical module for high school teachers to apply biology-math project-based learning (PjBL). This study supports digital-era education approaches that encourage critical thinking and cross-disciplinary problem-solving for Generation Z.

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1. INTRODUCTION

The world of education is currently on the verge of a major transformation driven by the Industrial Revolution 4.0 and Society 5.0 (Shahidi Hamedani et al., 2024; Ziatdinov et al., 2024). In this era, information is no longer linear but rather complexly interconnected. However, the reality in high school classrooms often demonstrates the opposite phenomenon. Education remains trapped in a "siloization" model, or a rigid separation between subjects. Biology is often perceived as merely a descriptive science that relies on memorization, while mathematics is viewed as a collection of abstract formulas far removed from real life (Kokkonen & Schalk, 2021; Lane, 2024).

This separation creates a cognitive gap for high school students. Yet modern scientific advances such as bioinformatics, epidemiology, and genetic engineering require a deep mastery of mathematics to understand the patterns of life (Abdi et al., 2024). Without strong integration, students will struggle to understand how digital data and algorithms now drive modern biological research (Christensen & Lombardi, 2020). This is the main challenge: how to create relevant learning amidst the digitalization that demands interdisciplinary thinking skills.

Data from various national and international assessments, such as PISA, often highlight the low numeracy literacy skills of students in Indonesia (Marhami et al., 2024; Megawati & Sutarto, 2021; Nurqamar & Nur, 2022). When students encounter biology problems that necessitate data analysis, this issue becomes even more evident (Anđić et al., 2024; Tan et al., 2023). For example, when studying ecology, students may be able to define a population, but they often fail when asked to predict its growth using linear or exponential mathematical models.

This fear of mathematics (math anxiety) also carries over into the biology laboratory (dos Santos Carmo & Crescenti, 2022). Many students avoid topics like genetics or metabolism because they involve calculating probabilities and biochemical stoichiometry (Bell et al., 2019; Cornish-Bowden & Hofmeyr, 2022). If left unchecked, such fears can result in high school graduates who struggle to interpret scientific data—a crucial skill in the era of misinformation and big data. So, a method is needed that teaches both "what" biology is and "how" math explains these processes.

The digital age offers unprecedented solutions. Simulation software, cloud-based data processing applications, and interactive visualization tools can bridge the gap between abstract mathematical concepts and concrete biological phenomena (Kantaros et al., 2025; Torre-Bastida et al., 2025). For example, by using spreadsheet software or genetic simulators, students no longer need to perform tedious manual calculations (Clemson et al., 2025). They can concentrate on conceptual comprehension: "What will be the effect on this biological system if this mathematical variable is altered?"

This approach fits well with the goals of the Independent Curriculum, which focuses on important learning and personal growth, reflecting the Pancasila-based student profile, especially in developing critical thinking skills. Digital technology enables broader exploration, allowing students to conduct virtual experiments that might be too expensive or dangerous in a physical laboratory (Shambare & Simuja, 2022). However, the use of technology without an appropriate pedagogical framework will only serve as a distraction (Flanigan & Babchuk, 2022; Martin et al., 2025). This is where the "Bio-Math Synergy" model plays a crucial role as a guide for integration.

Although the importance of this integration has been widely discussed theoretically (Gordon et al., 2022), its implementation at the high school level remains minimal. The main obstacles are subject-specific egos and a lack of teaching tools capable of harmoniously integrating the two fields. Biology teachers feel incompetent in teaching mathematics (Rozenszajn & Yarden, 2014), and math teachers feel they lack the context to teach biology (Uitto & Saloranta, 2017). As a result, integration occurs only superficially, such as simply counting the number of legs on an animal or adding up plant data without meaningful statistical analysis.

Furthermore, available learning resources are often conventional. Biology textbooks typically lack activities that enhance students' mathematical logic skills, and the reverse is also true. This situation creates an urgent need for research that develops practical learning models that can be implemented by teachers in the classroom without having to overhaul the entire curriculum but can have a significant impact on student learning outcomes.

This research stands out in comparison to previous studies. Unlike conventional integration research that only uses physical teaching aids (Almuhanna, 2025), "Bio-Math Synergy" utilizes a digital ecosystem (such as dynamic simulations and real-time data processing) tailored to the characteristics of Generation Z high school students. This research doesn't use boring mathematical examples but instead utilizes current issues such as modeling virus spread (learning from the COVID-19 pandemic) or analyzing genetic variation using probability logic, so students feel the knowledge they are learning is truly useful in their daily lives. The focus of this research is not solely on cognitive learning outcomes in one subject, but rather on improving interdisciplinary thinking skills—students' ability to seamlessly switch thinking modes from biological to mathematical to solve the same problem. Furthermore, the use of open-source and easily accessible digital tools ensures that this synergy model can be replicated by schools with limited facilities, not just elite schools.

We cannot delay any longer the urgency of integrating biology and mathematics within a single interdisciplinary learning framework. Without strong numeracy literacy, biology is merely a narrative without solid evidence (Aini et al., 2024). Conversely, without a biological context, mathematics for many students is simply a soulless numbers game (Borovik, 2021). This research offers a solution through the Bio-Math Synergy model. By harnessing the power of digital technology, it is hoped that high school students will become more than just consumers of information but also critical young analysts, able to read natural patterns through the lens of mathematical logic, and ready to face the challenges of higher education and the future world of work. This synergy enables biology and mathematics education to function collaboratively, fostering a holistic comprehension of life's complexities.

2. METHOD

This study used a quantitative approach with a Quasi-Experimental method. The design applied was a Pretest-Posttest Control Group Design. In this design, there are two groups that are not selected completely randomly (nonequivalent), namely the experimental group and the control group, to compare the effect of the treatment on the dependent variable. The design plan is presented in Figure 1 below.

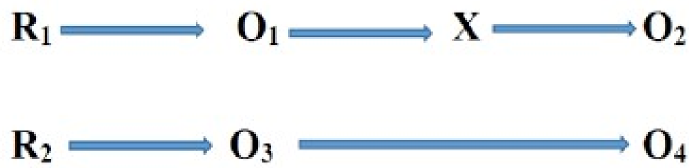

Figure 1. Pretest-Posttest Control Group Design

The population in this study was all eleventh-grade students at High School 1 Wajo and High School 7 Wajo. The two classes had similar initial abilities (based on report card grades or teacher recommendations). Class selection was conducted using purposive sampling. Class XI-A (Experimental): 35 students. Class XI-B (Control): 38 students.

The study was conducted through three main stages: (1) Preparation Stage: Developing learning materials (Bio-Math Synergy Module), test instruments, and conducting expert judgment validation. (2) Implementation Stage: Both groups were given a pretest. The experimental group was taught biology topic (genetics) by integrating the concept of mathematical probability using digital tools (spreadsheets and simulators). The control group was taught the same topic using separate lecture and discussion methods without explicit mathematical-digital integration. (3) Final Stage: Both groups were given a posttest with the same questions to assess the extent of student improvement.

The main instrument in this study was the Bio-Mathematical Literacy Test. This test consists of a complex essay or multiple-choice questions that require students to analyze biological data using mathematical formulas, read and interpret graphs of digital simulation results, and solve probability problems in the context of inheritance. In addition to the test, a Perception Questionnaire was also used to measure students' perceived level of learning relevance to the digital age.

The data obtained was statistically processed to test the research hypotheses:

- Prerequisite Tests: Includes the Normality Test (Shapiro-Wilk) and the Homogeneity Test to ensure the data is suitable for further analysis.
- N-Gain Test: Used to calculate the magnitude of improvement in ability between the pretest and posttest in both groups.
- t-Test (Independent Sample t-test): Used to test whether the difference in average improvement (N-gain) between the experimental and control classes is statistically significant at the 0.05 level.

3. RESULTS AND DISCUSSION

Results

Prerequisite Testing for Data Analysis

Before conducting the hypothesis testing, the pretest and posttest data were tested to ensure statistical validity.

- Normality Test: The Shapiro-Wilk test results indicated that the data in both classes were normally distributed ($p > 0.05$).

- Homogeneity Test: Levene's test results indicated that the data variance between the experimental and control classes was homogeneous ($p > 0.05$), allowing for further analysis using the t-test.

Description of Bio-Mathematical Literacy Skills

The data showed a significant increase in scores in both groups, but the experimental class using the Bio-Math Synergy model showed a sharper increase.

Table 1. Comparison of Bio-Mathematical Literacy Test Scores

Group	Pretest Average	Posttest Average	Upgrade (Points)
Experiment (XI-A)	52.14	84.57	32.43
Control (XI-B)	51.85	69.28	17.43

Overall, the data showed an increase in scores in both groups. However, the effectiveness of the learning model produced significantly different results between the experimental and control classes. Both classes started with nearly equal (homogeneous) initial abilities, with a tiny difference of only 0.29 points. Following the treatment, the experimental class achieved a significantly higher final score than the control class. The score increase in the experimental class was almost double that of the control class. The Bio-Math Synergy learning model proved to be far more effective in improving students' bio-mathematical literacy skills than conventional methods. The effectiveness was evident in the sharper score increase and posttest achievement that significantly exceeded that of the control class.

Effectiveness Analysis (N-Gain Test)

To measure the effectiveness of the treatment, a Normalized Gain (N-Gain) calculation was performed. The results indicated that the digital integration model had a "Moderate" to "High" impact on student achievement.

- Average N-Gain for the Experimental Class: 0.68 (Medium approaching High Category).
- Average N-Gain for the Control Class: 0.36 (Medium Low Category).

This indicates that integrating mathematics into biology using digital tools (such as spreadsheets for calculating genetic probabilities) is almost twice as effective in improving student understanding as conventional methods.

Hypothesis Testing (Independent Sample t-test)

Hypothesis testing was conducted on the N-Gain scores of both classes to determine the significance of the differences.

Table 2. Independent Sample T-test Results

Variable	t-count	df	Sig. (2-tailed)	Conclusion
N-Gain Literacy	6.42	68	0	H0 is rejected

The Sig. (2-tailed) value obtained is 0.000. In hypothesis testing, this value is compared with the commonly used significance level (alpha), which is 0.05. Because 0.000 < 0.05, statistically H_0 (Null Hypothesis) is rejected, and H_a (Alternative Hypothesis) is accepted. In addition, the T-count value shows 6.42. This high number indicates a large average difference between the two groups being compared (the experimental class and the control class). The N-Gain Score results indicate that the use of the Bio-Math Synergy model is much more effective in improving students' literacy skills compared to conventional teaching methods. The high t-count value and the significance value reaching 0 provide strong empirical evidence that the treatment provided has a real impact.

Results of the Digital Relevance Perception Questionnaire

Building upon the questionnaire distributed to the experimental class, students responded positively to this integration:

- 85% of students stated that using spreadsheets helped them understand that genetics is not just a theory, but rather the precise logic of probability.
- 90% of students felt better prepared for the digital age because they learned how to process raw data into biologically meaningful graphs.

Students in the experimental class proved more skilled at reading digital simulation graphs and analyzing probability data. For example, on the topic of Genetics, students in the control class tended to memorize the ratio 3:1, while students in the experimental class were able to mathematically prove why this number emerged through digital simulations of thousands of samples, making their understanding much more in-depth and relevant.

Discussion

The research results show that the implementation of the Bio-Math Synergy model had a significant positive impact on high school students' biomathematical literacy skills. The 0.68 increase in N-Gain in the experimental class proves that cross-disciplinary integration is not simply additional material, but rather a cognitive transformation. The following is an in-depth analysis of these findings:

Breaking Down Knowledge Fragmentation through Digital Integration

A major obstacle in conventional biology learning is knowledge fragmentation, where students study biology and mathematics in separate "silos." This phenomenon prevents students from seeing mathematics as an analytical tool in science.

The use of digital tools such as spreadsheets and interactive simulators in this model serves as a cognitive bridge. When students model Mendel's laws using probability logic on a computer, they no longer perform tedious manual computations. Instead of getting bogged down in arithmetic, they focus on the biological interpretation of the numbers. This aligns with Cognitive Load theory, which states that the use of technology can reduce extraneous cognitive load, freeing students' brain resources to understand higher-level concepts (Müller & Wulf, 2024; Skulmowski & Xu, 2022; Sweller, 2020).

Data Visualization: Transforming the Abstract into the Concrete

One interesting finding is the ability of students in the experimental class to interpret graphs. In conventional learning, population growth graphs are often seen as static images in textbooks. However, with the integration of mathematics, students understand that the graphs represent exponential or logistic functions.

Through digital simulations, students can manipulate variables (for example, changing the birth rate or environmental capacity) and see the graphs change instantly. This process builds "mathematical intuition" about biological phenomena. This ability is crucial in the digital age, where data literacy is a core competency. Students not only know "what" is happening to a population, but also understand "how" mathematical patterns explain these dynamics.

Relevance in the Digital Age and Learning Motivation

Perception questionnaire results showed a significant increase in learning motivation. Generation Z students tend to be more enthusiastic when they see direct applications of the science they are learning. By connecting biology (which is concrete/contextual) and mathematics (which is logical/abstract), students perceive a higher level of relevance in their learning.

The Bio-Math Synergy model provides a learning experience that mimics the workings of modern scientists. In the professional world, biology is inextricably linked to statistics and computing (Holmes & Huber, 2018; Weaver et al., 2017). By introducing this workflow at the high school level, we not only teach academic material but also equip students with the digital fluency needed for future STEM (Science, Technology, Engineering, and Mathematics) careers.

Novelty and Model Advantages

The main advantages of this model compared to previous integration research are its accessibility and adaptability. This research demonstrates that integration does not require expensive laboratory equipment. By utilizing open-source tools and basic mathematical logic, teachers can create a modern learning ecosystem. This novelty offers a practical solution to current curriculum challenges that require the simultaneous strengthening of literacy and numeracy.

The Bio-Math Synergy model has been empirically proven to significantly improve high school students' bio-mathematical literacy skills. This integration has successfully transformed students' perception of mathematics from a daunting subject to an essential tool for understanding life. Digital technology plays a central role in uniting these two disciplines, creating learning that is not only academically intelligent but also relevant to the demands of the times.

4. CONCLUSION

The implementation of the Bio-Math Synergy model has been proven to significantly improve high school students' biomathematical literacy skills. This is demonstrated by the significantly higher N-Gain score of the experimental class (0.68) compared to the control class (0.36), as well as the statistically significant t-test results. The integration of digital tools (such as spreadsheets and simulators) acts as a catalyst, transforming abstract mathematical concepts into concrete biological analysis tools. This technology makes it easier for students to visualize data, perform population modeling, and understand dynamic genetic probabilities. Furthermore, this model successfully breaks down the dichotomy between biology and mathematics. Students no longer view the two disciplines in isolation but rather as a synergy relevant for solving complex problems in the digital age. This has resulted in increased student motivation and self-efficacy for materials involving data calculations.

As a recommendation, schools are advised to facilitate collaboration between biology and mathematics teachers to design integrated learning modules so that students gain a holistic perspective. Educators should further optimize freely available (open-source) software to strengthen data analysis in biology labs so that students become accustomed to a culture of computational thinking. This research is limited to the topics of genetics and ecology. Future researchers are advised to explore integration in other topics such as physiology (with gas laws/fluid flow) or microbiology (with logarithmic bacterial growth). Considering this research used a quasi-experimental design in one school, it is recommended to conduct research on a wider scale (multi-school) to generalize the effectiveness of the Bio-Math Synergy model across various student ability levels.

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