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The effectiveness of collaborative learning based on mobile learning in a learning management system to improve science competence in biology education students

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Abstract: This study aims to examine the effectiveness of a collaborative learning model integrated with a mobile learning-based Learning Management System (LMS) in improving science competence among Biology Education students. A quasi-experimental design with a nonequivalent control group was employed, involving 108 students from the Biology Education Program at ISC Dili, Timor-Leste, divided equally into experimental and control groups. The experimental group received treatment using a mobile LMS-based collaborative learning approach, while the control group was taught using conventional methods. Data were collected through pretest and posttest instruments and analyzed using normality, homogeneity, independent t-tests, and N-gain analysis. The findings indicate a statistically significant improvement in the experimental group's posttest scores ($M = 81.69$) compared to the control group ($M = 68.13$), with a significance level of $p = 0.001$. The N-gain score of 1.14 further confirms the higher effectiveness of the experimental intervention. This study concludes that collaborative learning supported by mobile LMS is significantly more effective than traditional methods in enhancing science competence. Practical implications suggest that educators and institutions should consider adopting mobile LMS-based collaborative learning to foster deeper engagement, critical thinking, and science mastery, particularly in digitally evolving educational environments.

Keywords: *Biology education, Effectiveness of collaborative learning, Science competency.*

1. Introduction

Collaborative learning is an approach recognized in the field of education to enhance student participation and interaction. This method emphasizes cooperation among students in completing tasks, where each group member plays an active role and contributes to achieving a common goal [1, 2].

This approach supports the exchange of knowledge and skills among students, thereby deepening their understanding of academic concepts [3, 4]. Additionally, the flipped classroom method has also been proven to positively contribute to student learning, particularly in enhancing the effectiveness of collaborative learning [5, 6].

Collaborative learning based on mobile learning in Learning Management Systems (LMS) has become an increasingly relevant topic in higher education, especially in enhancing science competencies among biology education students. Mobile learning offers universal access to educational materials and enables flexible learning anywhere and anytime [5, 6]. Additionally, collaborative learning methods have been proven to enhance motivation, interaction between students and teachers, as well as problem-solving abilities [7, 8]). In the context of science education, the use of mobile technology can provide relevant and authentic learning scenarios, which are important for understanding complex concepts [9, 10].

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Mobile learning platforms have evolved to support dynamic collaborative environments. According to Alshammari and Alkhabra [11] mobile learning enhances students' motivation and continuous learning when supported by high levels of self-regulation and system usability. Similarly, Wu, et al. [12] found that integrating immersive tools such as 360-degree video and virtual reality in LMS can increase engagement and improve learning retention in science education. Furthermore, Wang, et al. [13] developed a deep learning-based framework showing how LMS analytics can predict student performance and support effective group collaboration. This aligns with the work of Kharismawati, et al. [14] who emphasized that LMS-supported collaboration enables personalized learning, particularly in science subjects where abstract concepts require contextual understanding. Despite the benefits, some challenges remain in implementing mobile LMS systems effectively. Issues such as technological readiness, digital literacy, and instructional design quality are critical to consider [15]. Addressing these challenges is essential to optimize LMS usage in enhancing science competence.

Although many studies have shown the effectiveness of collaborative learning based on mobile learning, there are still several gaps that present opportunities in this research; for example, most studies focus more on the pedagogical opportunities offered by mobile technology, while technological aspects such as hardware and software issues are still underexplored [9]. This is important to ensure the quality of service in mobile-based collaborative learning activities. Similarly, several other studies have not specifically evaluated the effectiveness of certain LMS in supporting mobile-based collaborative learning. Further research is needed to understand how LMS can be optimized to support effective interaction and collaboration [16, 17]. Meanwhile, Santoso [18] in his research, showed that mobile-based collaborative learning strategies are more effective if students have a high level of Self-Regulated Learning (SRL) [19]. However, there is still little research exploring how to integrate strategies to enhance SRL in the context of mobile-based collaborative learning. Most of the existing studies were conducted in the context of general education or other fields of study, not specifically in biology education. Further research is needed to evaluate how this method can be effectively applied to enhance science competence among biology education students [20].

The use of Learning Management Systems (LMS) in the world of education has experienced rapid development over the past few decades, in line with the increasing integration of digital technology in the teaching and learning process. Alem [21] states that LMS is an online platform that facilitates the management, distribution, and evaluation of learning, thus becoming the main solution to overcoming the challenges of distance learning [22] highlight how LMS can enhance student engagement in online learning environments at universities. Meanwhile, Bervell and Arkorful [23] examine the factors that influence the utilization of LMS in online learning, including supportive conditions and user behavior.

In East Timor, the COVID-19 pandemic has encouraged the use of LMS at various levels of education, including higher education, as an effort to meet the need for effective learning even when conducted online [24]. LMS provides a variety of features that enable interaction between instructors and students, such as discussion forums, assignment submissions, online quizzes, and the provision of structured learning materials. With LMS, students can access materials more flexibly, while instructors can better monitor student progress and participation. Soares, et al. [25] to support educational planning in East Timor by integrating smart technology and innovative practices in higher education. More efficiently, thereby improving the quality of learning and facilitating better learning outcomes. However, [26] the COVID-19 pandemic caused the closure of schools in more than 190 countries, prompting innovations in online learning through radio, television, and self-study packages.

The effectiveness of LMS in learning depends on user readiness, technological infrastructure, and pedagogical approaches. In East Timor, key challenges include limited internet access, lack of instructor training, and minimal meaningful interaction in online learning. LMS use has positively impacted student engagement, especially online [27] as it offers features enabling collaboration, such as discussion forums, group assignments, and chat rooms [28]. Integrating collaborative learning and LMS creates a dynamic, interactive environment that supports mastery of complex scientific concepts.

Mastery of scientific concepts plays a crucial role in higher education, especially for students pursuing studies in the field of science [29]. A deep understanding of scientific concepts enables students to master the fundamental principles that form the foundation of the disciplines they study [30]. However, there are still significant challenges in improving the mastery of scientific concepts. Several studies reveal that students often struggle to understand scientific concepts that are abstract and complex [31]. These constraints are exacerbated by several factors, such as limited supporting facilities, suboptimal teaching quality, and a less innovative learning approach [32]. These factors contribute to the low level of students' understanding of scientific concepts [33] .

Learning Management System (LMS) is an online learning platform designed to support the integrated teaching and learning process [34-36]. Mobile learning-based development Learning Management System is a breakthrough in the field of education, aimed at creating a personalized learning experience according to students' learning styles [37]. With this approach, the LMS is expected to serve as a foundation for the formation of study groups (collaborative learning), organized based on students' interests and learning styles [38].

In the ongoing development of educational innovations, the utilization of Information and Communication Technology has brought significant transformations in the teaching methods applied by educators, including lecturers who use them [39, 40]. In line with these changes, the utilization of Learning Management Systems (LMS) also provides beneficial opportunities to enhance science competence among biology education students. With the benefits of this approach, biology education students are prepared to become future educators

Efforts to improve science competence among biology education Students to become future educators. can be done by implementing collaborative learning strategies, with an LMS to realize it [41]. This collaborative learning approach involves active interaction and cooperation among students, which collectively fosters a deeper understanding of fundamental scientific concepts as well as the development of critical thinking skills [42].

Mobile learning-based LMS enhances science learning by improving understanding, motivation, and effectiveness through interactive features [43]. In clinical education, it supports knowledge improvement in surgical nursing, though it shows no significant impact on self-efficacy. Still, it is recommended for clinical training [44]. M-learning impacts perceived usefulness and should be considered in application development and institutional strategies [11].

During group collaboration, LMS analyzes data to give feedback, suggest activities, and guide members accordingly [45] . It also improves communication and collaboration intensity through online discussions, idea exchange, and resource sharing—helping students overcome time and space limits, solve problems, and boost creativity [36, 46, 47].

The novelty of this research lies in developing a mobile-based LMS that predicts students' learning styles and forms study groups. Through collaborative learning, students can interact and discuss with peers. This approach is designed to enhance the science competencies of biology students and contributes to the future development of digital learning.

2. Literature Review

2.1. Collaborative Learning in Biology Education

Collaborative learning is a pedagogical approach that positions students as active participants through group-based interaction, discussion, and problem-solving. This method is particularly effective in biology education, where students often need to grasp complex systems such as genetics, ecosystems, and cellular processes. According to Laal and Laal [48] collaborative learning enhances conceptual understanding and retention through social construction of knowledge. Recent studies by Moreno, et al. [49] and Nguyen, et al. [50] demonstrate that collaborative learning significantly improves metacognitive awareness and conceptual mastery, especially when integrated with project-based learning and authentic assessment in science classrooms.

2.2. Mobile Learning (M-Learning) for Accessibility and Cognitive Development

Mobile learning (m-learning) enables students to access educational content flexibly, anytime and anywhere, which supports personalized learning experiences. According to Alshammari and Alkhabra [11] m-learning increases learner motivation and continuous engagement, particularly when students demonstrate high levels of self-regulation and digital literacy. Wu, et al. [12] found that mobile learning embedded with virtual reality and gamified elements enhances learner interaction and comprehension in science education. Hwang, et al. [5] also report that mobile learning tools with real-time feedback mechanisms and visualization features can support students in mastering abstract biological concepts.

2.3. The Role of Learning Management Systems (LMS) in Supporting Collaboration

Learning Management Systems (LMS) are integral platforms that organize content, track learner progress, and support interaction. When embedded with mobile access and analytics, LMS platforms can facilitate collaborative learning through features such as group formation, automated feedback, discussion forums, and learning dashboards Wang, et al. [13]. Rohani and Jamaludin [51] emphasized that LMS-supported collaboration can provide differentiated instruction tailored to learning styles and performance levels. Moreover, LMS can function as a predictive tool to assess and enhance group dynamics and knowledge sharing in science classrooms.

2.4. Science Competence: Dimensions and Pedagogical Implications

Science competence includes not only the mastery of content knowledge but also critical thinking, scientific reasoning, and the application of concepts to real-life contexts [52]. Studies have shown that integrating collaborative learning with mobile LMS platforms leads to a statistically significant improvement in science competence. Fang, et al. [42] argue that collaborative tasks such as scientific argumentation and group reflections foster higher-order thinking and procedural understanding. Likewise, Metha and Zhao [53] found that LMS-enhanced collaboration promotes deeper conceptual learning through structured interaction and immediate formative feedback.

3. Methodology

The approach used in this research is a quantitative research approach. Quantitative research is a type of research that generally uses statistical analysis [54]. The research type in this study is quasi-experimental. The design used is a nonequivalent control group design, with two groups: the experimental group receiving collaborative learning via a mobile learning-based LMS and the control group using conventional learning. This design allows researchers to compare results between the two groups to assess the learning model's effectiveness [55].

Table 1.
Research Design.

Group	Pre-test	Treatment	Posttest
Experimen	*R1*	*X1*	*R2*
Control	*R3*	*X2*	*R4*

Note:
R1: Pretest in the experimental group
R2: Posttest of science competency in the experimental group
R3: Pretest of science competence in the control group
R 4: Science competency posttest in the control group
X 1: The treatment uses collaborative learning with a mobile learning-based LMS in the experimental group.
X2: The treatment uses a conventional model in the control group.

The participants in this study are students of the Biology Study Program, Faculty of Education Sciences, Instituto Superior Cristal, Dili, who were selected using cluster random sampling, which is a regional sampling technique used to determine the sample when the object to be studied or the data source is extensive [56].

From a total population of 180 students, 108 participants were selected and divided into an experimental group consisting of 54 students and a control group also consisting of 54 students. This study's data collection method used a test consisting of 5 open-ended questions to obtain data related to science competency [57]. The data analysis method includes normality and homogeneity prerequisite tests, followed by the independent sample t-test and N-gain test [58].

4. Results and Discussion

In this study, initial data were obtained from pretest data given to assess students' early science competencies before implementing collaborative learning using a mobile learning-based LMS. The pretest was given to the experimental class and the control class. The final data obtained is in the form of a posttest, which serves as a measure of students' science competence after implementing collaborative learning using a mobile learning-based LMS. The posttest was also given to the experimental class and the control class. The results obtained are presented in a summary of descriptive data shown in Table 2.

Table 2.
Recapitulation of descriptive data on students' pretest and posttest scores.

Group	Average Pre-test	Average Posttest
Control	48.94	68.13
Experiment	47.89	81.69

Table 2 shows the average pretest science competency score in the control class was 48.94, and the average posttest science competency score in the control class was 68.13. Meanwhile, the average pre-test science competency score in the experimental group was 47.89, and the average post-test science competency score in the experimental group was 81.69.Normality testing was conducted using the Shapiro-Wilk test, with calculations performed using SPSS 26 software. If the Sig value is greater than 0.05, then the data is considered normal; if not, it is considered not normal. This test is used to determine whether the obtained data is normally distributed or not. The results of the normality test calculations for the essay test can be seen in Table 3.

Tabel 3.
Results of Normality Test for Pretest and Posttest.

Group	Shapiro Wilk (Pretest)	Shapiro Wilk (Posttest)
Control	0.061	0.184
Experiment	0.065	0.058

Table 3 shows that the results of the normality test for the control and experimental groups have Sig values > 0.05. Therefore, it can be concluded that both data groups are normally distributed.

The homogeneity test is conducted to determine whether the data from both research samples have homogeneous or heterogeneous variances. If the Sig value > 0.05, it is said to be homogeneous; if not, it is said to be non-homogeneous or heterogeneous. The results of the calculations obtained are as follows:

Tabel 4.
Results of Homogeneity Test for Pretest and Posttest.

	Df1	Df2	Sig
Pre-test	1	134	0.842
Post-exam	1	134	0.146

Table 4 shows that the results of the homogeneity test have a Sig value > 0.05. Therefore, it can be concluded that the obtained data group is homogeneous. In this study, hypothesis testing was also conducted using the t-test to determine whether there is a difference in students' science competencies between the control class and the experimental class. If the Sig value > 0.05 indicates no difference in science competence, conversely, if the Sig value > 0.05 indicates a difference in science competence between the control class and the experimental class.

Tabel 5.
Results of Pretest t-test.

	Sig (2-tails)
Science Literacy	0.841

Table 5 shows the t-test results for the pre-test, with a probability value of 0.841. Because the probability is 0.841 > 0.05, this indicates that there is no significant difference in initial science competence between the control class and the experimental class.

Tabel 6.
Results of Post-Test t-test.

	Sig (2-tails)
Science Literacy	0.001

Based on Table 6, the posttest t-test results show a probability of 0.001. Because the probability value of 0.001 is less than 0.05, it can be concluded that there is a very significant difference in science competence between the control class and the experimental class.

The N-gain test is used to evaluate and strengthen the effectiveness of implementing collaborative learning integrated with LMS. To interpret the effectiveness value of the N-gain score [59, 60]. See the table below:

Tabel 7.
Interpretation Categories of N-Gain Effectiveness.

Persentase (%)	Interpretation
< 40	Ineffective
40 – 55	Less effective
56 – 75	fairly effective
> 76	Effective

$$efectiveness = \frac{N - (\,experiment)\ group\,)}{N - gain\ (\,control\ group\,)}$$

The criteria used to determine which learning method is more effective between collaborative learning using an M-learning-based LMS and conventional learning are as follows:

- If the effectiveness > 1, this indicates a difference in effectiveness, where collaborative learning using a mobile learning-based LMS is considered more effective than conventional learning.
- If effectiveness = 1, there is no difference in effectiveness between collaborative learning using a mobile learning-based LMS and conventional learning.
- If the effectiveness is < 1, there is a difference in effectiveness where conventional learning is considered more effective compared to collaborative learning using a mobile learning-based LMS

Table 8 shows the percentage N-gain values obtained through SPSS testing as follows:

Tabel 8.
Results of N-Gain Test.

Group	Mean		Std. Error
N-gain (%)	Control	70.5611	1.92079
	Experiment	80.5911	1.64537

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Table 8 shows the results of the N-gain percentage test, which yields the average N-gain percentage. For the experimental group, the average was 80.59%, which is categorized as effective (see Table 7), while the average N-gain percentage for the control group was 70.56%, which is categorized as moderately effective (see Table 7).

$$efectiveness = \frac{80,59}{70,56}$$

$$efectiveness = 1,14$$

Based on the effectiveness test criteria, the effectiveness test result of 1.14 > 1 indicates a difference in effectiveness where learning with the collaborative learning model using a mobile learning-based LMS is stated to be more effective in improving students' science competencies compared to conventional learning models.

5. Discussion

The results from this study include pretest and posttest data of students' science competencies in two groups: the control group using conventional learning and the experimental group applying collaborative learning via a mobile learning-based Learning Management System (LMS). The control group's average pretest score was 48.94, increasing to 68.13 on the posttest. The experimental group had a pretest average of 47.89 and a posttest score of 81.69, showing greater improvement in science competence. The homogeneity test (Sig > 0.05) indicates comparable score distributions in both groups. The pretest t-test showed a probability of 0.841 (> 0.05), indicating no initial ability difference. Meanwhile, the posttest t-test with a probability of 0.001 (< 0.05) shows a highly significant difference in science competence between the groups after treatment.

The effectiveness of collaborative learning using a mobile learning-based LMS is further evidenced by an effectiveness test result of 1.14, indicating that this method is highly effective (greater than 1) in improving science competencies. According to research [61-63]. Technology-based approaches such as mobile learning-based LMS have significant potential to enhance student engagement and learning outcomes, particularly in facilitating collaborative interactions and broader access to educational resources. This aligns with the findings of this study, where the use of a mobile learning-based LMS allows students to access materials more flexibly, engage in deeper discussions, and enhance their understanding of concepts through collaboration with classmates.

The discussion of the research results shows that using collaborative learning methods through mobile learning-based Learning Management Systems (LMS) is more effective in improving students' science competencies than conventional methods. With a higher effectiveness score of 1.14, this study reinforces the argument that collaborative learning with mobile learning-based LMS can facilitate interaction, access to materials, and deeper conceptual understanding. This is highly relevant in the rapidly evolving digital era, where education increasingly utilizes technology to support learning. Additionally, this research aligns with the educational paradigm shift in the digital era. Previous studies show that technology in education can create interactive environments supporting critical understanding through richer, more varied media [27, 64-66].

In this context, LMS use not only simplifies access to materials but also enables a more intensive and meaningful collaborative process, ultimately leading to positive learning outcomes. These findings strengthen the view that educational technology, particularly collaborative learning using mobile learning-based LMS, significantly improves student outcomes, especially in mastering complex science competencies.

Other research supports the finding that collaborative learning using mobile learning-based LMS significantly improves science competencies. Studies show that technology-integrated collaborative learning, such as LMS, enhances student motivation [53, 67, 68]. LMS enables dynamic interactions through features like discussion forums, automated assessments, and instant feedback, improving engagement and conceptual understanding. This is evident in this study, where the experimental group showed significant improvement in science literacy..

Furthermore, previous research highlights that technology-supported collaboration helps develop critical thinking and deeper understanding [69-71]. Collaborative learning fosters open, reflective discussions, allowing students to learn from peers' perspectives. This is why the experimental group showed greater improvement than the control group.

These findings are supported by previous research conducted by Rohani and Jamaludin [51]; Hwang and Wu [72] and Zheng, et al. [73] which found that mobile learning-based LMS technology offers personalized learning, allowing students to access materials based on their needs and review challenging topics, which is not always possible in traditional face-to-face learning. This flexibility enhances deeper understanding, as evidenced by the significantly higher post-test scores in the experimental group.

Studies emphasize that mobile learning-based LMS in collaborative learning provides flexibility and encourages meaningful student interactions. This supports the idea that technology-based learning, especially through LMS, benefits modern education by enhancing collaboration and deep understanding [74-76]. LMS is not just a content delivery tool but a platform for active engagement, collaboration, and independent learning, significantly improving student outcomes, especially in mastering complex concepts like science.

This study contributes to modern learning theory by showing how technology-based collaborative learning can improve student outcomes. The effectiveness of LMS use supports its role in enhancing conceptual understanding over conventional methods. It offers practical guidance for educators to design strategies that promote interaction and deeper learning. Institutions can integrate LMS into broader learning programs and curricula, fostering more interactive, adaptive learning experiences. Overall, this research supports both

6. Conclusions

The most important conclusion of this study is that collaborative learning using a mobile learning-based learning management system (LMS) is more effective in enhancing students' understanding of science competencies compared to conventional methods. With the significant improvement in posttest results for the experimental class, this research emphasizes that integrating technology and collaboration in learning can improve students' understanding of complex material

Further implications for this field highlight the need for higher education institutions to consider broader use of Learning Management Systems (LMS), particularly for learning that requires deep conceptual understanding. This also opens opportunities to develop more innovative, technology-based learning models to improve student learning outcomes.

The benefit of this research lies in empirical evidence supporting the effectiveness of Learning Management Systems (LMS) in education, particularly in science. However, one limitation of this study is the limited sample coverage, which can affect result generalization. In addition, this study focuses on one field (science), so the method's effectiveness in other areas still requires further testing.

For future research, it is recommended that studies be conducted with larger and more diverse samples, encompassing various disciplines to explore how LMS and collaborative methods can be adapted in different educational contexts. Further research could also investigate factors such as students' learning styles, motivation levels, and digital skills, which may affect the effectiveness of collaborative learning using mobile learning-based LMS

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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