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QR Code-Based Interactive Learning to Improve Students' Reasoning Ability in the Physics Topic of Physical Quantities, Units, and Measurement

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Abstract

This study looked into how using QR codes for interactive learning works and how it affects students' misunderstandings and their ability to reason when learning about quantities, units, and measurements. The study used a quantitative quasi-experimental design that included a pretest and posttest with a control group. The study involved 105 students from Grade X at SMA Negeri 1 Cerme.There was one control class, X-7, and two experimental classes, X-10 and X-12. Each class had 35 students. Data was gathered through learning implementation observation forms, diagnostic and reasoning ability assessments, and questionnaires that collected student responses. The data were looked at using descriptive statistics, tests to check if certain conditions were met, paired-samples tests, N-gain tests, analysis of variance, and measures of how big an effect was. The use of QR code-based interactive learning rose from 84.25% in the first session to 91.14% in the third session and was considered very good. The N-gain score was 0.29 in the control class, 0.53 in class X-10, and 0.49 in class X-12. The ANOVA results indicated that there was a significant difference in how much each class improved in learning, with a significance level of 0.001. The effect size was 1.12, which shows a big impact on learning. Students gave good responses, and the average scores were higher than 80%. These results show that using QR codes for interactive learning can help students think more deeply and explore physics ideas better. More studies should look at both results together by using full data from each person and by having a longer time period for the intervention.

Keywords: *QR Code-Based Learning, Physics Education, Misconceptions, Reasoning Ability*

Pembelajaran Interaktif Berbasis Kode QR untuk Meningkatkan Kemampuan Penalaran Siswa pada Materi Besaran, Satuan, dan Pengukuran Fisika

Abstrak

Penelitian ini mengkaji penerapan pembelajaran interaktif berbasis kode QR serta pengaruhnya terhadap miskonsepsi dan kemampuan penalaran siswa dalam mempelajari materi besaran, satuan, dan pengukuran. Studi ini menggunakan desain kuasi-eksperimental kuantitatif yang mencakup tes awal (pretest) dan tes akhir (posttest) dengan kelompok kontrol. Subjek penelitian terdiri dari 105 siswa kelas X di SMA Negeri 1 Cerme, yang

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terbagi menjadi satu kelas kontrol (kelas X-7) dan dua kelas eksperimen (kelas X-10 dan X-12), dengan masing-masing kelas beranggotakan 35 siswa. Data dikumpulkan melalui lembar observasi keterlaksanaan pembelajaran, asesmen diagnostik dan kemampuan penalaran, serta kuesioner untuk menjaring respons siswa. Analisis data dilakukan menggunakan statistik deskriptif, uji prasyarat, uji sampel berpasangan (paired-samples test), uji N-gain, analisis varians (ANOVA), serta perhitungan ukuran efek (effect size). Tingkat keterlaksanaan pembelajaran interaktif berbasis kode QR meningkat dari 84,25% pada pertemuan pertama menjadi 91,14% pada pertemuan ketiga, yang dikategorikan sangat baik. Skor N-gain yang diperoleh adalah 0,29 untuk kelas kontrol, 0,53 untuk kelas X-10, dan 0,49 untuk kelas X-12. Hasil ANOVA menunjukkan adanya perbedaan yang signifikan dalam peningkatan pembelajaran antar kelas, dengan tingkat signifikansi 0,001. Ukuran efek sebesar 1,12 menunjukkan dampak yang besar terhadap pembelajaran. Respons siswa tergolong positif, dengan skor rata-rata di atas 80%. Hasil ini menunjukkan bahwa pembelajaran interaktif berbasis kode QR dapat membantu siswa berpikir lebih mendalam dan mengeksplorasi konsep-konsep fisika dengan lebih baik. Penelitian selanjutnya disarankan untuk menganalisis hasil secara lebih komprehensif dengan menggunakan data individu secara lengkap serta menerapkan intervensi dalam rentang waktu yang lebih lama.

Kata kunci : Pembelajaran Berbasis Kode QR, Pendidikan Fisika, Miskonsepsi, Kemampuan Penalaran

INTRODUCTION

Physics learning requires students to understand scientific concepts, interpret physical phenomena, and apply quantitative relationships to explain natural events. The development of digital technology has created opportunities to support these learning processes through interactive and technology-integrated learning environments. The integration of digital technology into physics learning has been explored as an approach to addressing conceptual difficulties and supporting students' engagement with scientific concepts (Khairani et al., 2025). However, the use of technology alone does not guarantee meaningful learning. Students still need instructional activities that encourage them to analyze information, construct explanations, and connect scientific concepts with observable phenomena. These abilities are particularly important in physics because conceptual understanding and scientific reasoning are closely related to students' ability to solve problems and interpret experimental results.

One of the fundamental topics in physics is physical quantities, units, and measurement. These concepts provide the basis for understanding physical phenomena and conducting scientific investigations. Students are expected to distinguish between

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base and derived quantities, understand relationships between quantities and their units, select appropriate measurement instruments, and interpret measurement results. Nevertheless, students may experience difficulties in understanding these concepts, particularly when connecting physical quantities with their corresponding (A'yun & Wilujeng, 2024) . Difficulties in understanding measurement uncertainty and interpreting experimental data have also been reported in physics learning (Mahdiannur, 2024) . Furthermore, misconceptions involving physical quantities and measurement accuracy have been identified among Grade X students (Bahrami, 2025) . These difficulties indicate that learning measurement concepts requires more than memorizing definitions and procedures; students need opportunities to analyze measurement information and construct scientifically appropriate explanations.

Conceptual difficulties in physics are also associated with students' prior knowledge and alternative conceptions. A review of high school physics misconceptions has identified misconceptions as an important issue that requires systematic investigation and appropriate instructional responses (Damarsha et al., 2023). Diagnostic instruments can help identify students' alternative conceptions and provide information for designing appropriate learning interventions (Budiyono et al., 2025) . The remediation of physics misconceptions has also been discussed through various instructional strategies, highlighting the importance of conceptual reconstruction during learning (Putu Nita Kusuma & Redhana, 2025) . In addition, research on student misconceptions in parabolic motion demonstrates the need to examine students' conceptual understanding through diagnostic assessment rather than relying solely on achievement scores (Roslina et al., 2025) . Therefore, physics instruction needs to provide learning experiences that enable students to identify relevant information, examine conceptual relationships, and justify their understanding using scientific principles.

In addition to conceptual understanding, reasoning ability is an important outcome in physics learning. Students need reasoning skills to identify relevant information, analyze relationships between physical quantities, interpret experimental data, and draw conclusions. Research on scientific reasoning among high school students has highlighted the importance of this ability in physics learning (Dinata et al., 2025) . Science process skills are also associated with students' ability to construct arguments

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and communicate explanations based on scientific evidence (Darmaji et al., 2022). Furthermore, the development of explanation, conclusion, and evaluation skills has been investigated through STEM-based student worksheets and contextual problems (Kiswari et al., 2023). These findings suggest that learning activities should provide opportunities for students to engage in scientific reasoning rather than focus exclusively on procedural exercises.

Digital learning media offer opportunities to provide students with visual explanations, interactive representations, and additional learning resources. The use of virtual laboratories, for example, has been examined as a means of supporting higher-order thinking skills in physics learning (Darwis & Hardiansyah, 2023). Digital physics learning resources have also been reviewed for their potential to support more meaningful teaching and learning experiences (Faresta et al., 2024). In addition, digital learning media can be developed through different formats, such as web-based comics and visual representations, to help students explore scientific concepts (Setiani et al., 2021). The integration of digital resources with inquiry-based activities has also been investigated in physics learning, particularly in supporting students' engagement with scientific concepts (Syukri et al., 2022). These studies indicate that digital media can provide additional learning opportunities when their use is connected to meaningful instructional activities.

One technology that can connect printed learning materials with digital resources is the Quick Response (QR) code. QR codes allow students to access additional learning content through mobile devices, including explanations, videos, simulations, and exercises. Previous research has examined the integration of QR codes into physics learning modules to support students' learning interest and digital literacy (Anggraeni et al., 2022). QR code-based physics learning media have also been developed using Google Sites for the topic of particle dynamics (Prihatiningtyas et al., 2022). Another study introduced a QR-code-assisted learning book as a resource for science-based physics learning (Bakri et al., 2020). The use of QR codes in educational settings has also been examined in relation to students' perceptions of accessing digital learning resources in large classrooms (Abdul Rabu et al., 2019). Furthermore, QR code integration in textbooks has been explored through augmented reality to enhance student performance in educational settings (AlNajdi, 2022). These studies demonstrate

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the potential of QR codes to connect conventional instructional materials with accessible digital content.

Although previous studies have examined digital learning media, QR code integration, physics misconceptions, and students' reasoning ability, these research areas have generally emphasized different outcomes and instructional contexts. Research on QR code-based physics modules has focused on learning interest and digital literacy (Anggraeni et al., 2022), while other studies have developed QR code-supported media for specific physics topics (Prihatiningtyas et al., 2022). Research on measurement concepts has examined critical reasoning through differentiated STEAM learning (Rosady Putri et al., 2025). Meanwhile, studies on physics misconceptions have focused on diagnostic identification and remediation through other instructional approaches (Azahra & Wasis, 2024). Thus, a research gap remains concerning the integration of QR code-supported interactive activities into printed physics worksheets specifically designed for physical quantities, units, and measurement, while examining students' reasoning ability as the main learning outcome.

The research context is Grade X physics learning at SMA Negeri 1 Cerme, Gresik Regency. The initial assessment conducted before the instructional intervention showed average pretest scores of 63.45 in class X-7, 65.22 in class X-10, and 64.18 in class X-12. The scores indicate that the three classes had relatively similar initial performance, providing a baseline for evaluating changes following the learning intervention. However, these pretest scores alone do not establish the specific conceptual difficulties experienced by students. Therefore, the instructional approach in this study was designed to provide additional opportunities for students to explore measurement concepts through printed worksheets integrated with digital learning resources.

The present study addresses the identified gap by integrating QR codes into printed physics worksheets that provide access to conceptual explanations, instructional videos, simulations, examples, and problem-solving activities. Unlike studies that primarily focus on the development of QR code-based media, learning interest, or digital literacy, this study emphasizes the integration of QR code-supported learning activities with the assessment of students' reasoning ability in the specific topic of physical quantities, units, and measurement. Students are encouraged to identify physical quantities, analyze relationships between quantities and units, interpret

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measurement results, explain their answers, and draw conclusions based on scientific information. The unique part of this study is how it combines printed and digital learning materials to help students engage in reasoning activities when learning about physics measurements.

This study looks at how QR code-based interactive learning is being used and checks how it affects students' reasoning skills when learning about physical quantities, units, and measurement for Grade X students at SMA Negeri 1 Cerme. The study is expected to provide an alternative approach to physics instruction by connecting printed learning materials with accessible digital resources and providing opportunities for students to develop their conceptual understanding and scientific reasoning through measurement-related learning activities.

RESEARCH METHODS

This study employed a quantitative quasi-experimental design using a pretest-posttest control group design. The design was selected to examine the effect of QR code-based interactive learning on students' misconceptions and reasoning ability when individual random assignment was not feasible in the school setting. Quasi-experimental designs are commonly used to evaluate instructional interventions in naturally formed classroom groups (Anggriani et al., 2022) . The study involved one control class and two experimental classes. The experimental classes received QR code-based interactive learning, while the control class received conventional physics instruction without QR code-based learning media. In the research design, O_1 represented the pretest, X represented the treatment, and O_2 represented the posttest.

The research was conducted at SMA Negeri 1 Cerme, Gresik Regency, during the odd semester of the 2025/2026 academic year under the Merdeka Curriculum. The population consisted of all Grade X students from classes X-1 to X-12. The sample was selected using purposive sampling because the research required intact classes with relatively similar academic characteristics, the same curriculum, equal learning time, and no previous experience with QR code-based interactive learning. Purposive sampling is commonly used when participants are selected according to criteria relevant to the research objectives(Etikan, 2017). Individual random assignment was not applied because the school had already organized students into permanent classes, making it impractical to reorganize students for the research treatment.

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Three classes were selected as participants. Class X-7 served as the control class, while classes X-10 and X-12 served as the experimental classes. Each class consisted of 35 students, resulting in a total sample of 105 students. The control class received conventional physics instruction using standard teaching materials. The experimental classes received QR code-based interactive learning on quantities, units, and measurements. The school, grade level, teaching staff, learning material, time allocation, and assessment procedures were controlled across the three classes to reduce the influence of external factors. The learning material consisted of quantities, units, and measurements. The material included physical quantities, base quantities, derived quantities, units, unit relationships, measurement instruments, accuracy, precision, measurement results, and measurement uncertainty. The learning materials were presented through printed worksheets integrated with QR codes. The QR codes provided access to conceptual explanations, instructional videos, simulations, examples, and problem-solving activities. QR codes can connect printed learning materials with digital resources accessed through mobile devices (Abdul Rabu et al., 2019).

The variable being tested was interactive learning through QR codes. The variables being studied were students' misunderstandings and their ability to reason. Misconceptions referred to students' scientifically incorrect understanding of quantities, units, measurement results, accuracy, precision, and measurement uncertainty. Reasoning ability referred to students' ability to identify relevant information, analyze relationships between quantities and units, interpret measurement data, provide explanations, and draw conclusions (Sihombing & Yohandri, 2025) . The control variables included the school, grade level, learning material, learning time allocation, teaching staff, and assessment instruments. Data were collected using learning implementation observation sheets, diagnostic and reasoning ability tests, and student response questionnaires (Warsi & Rani, 2024) . The use of several data collection techniques provided information about the implementation of learning activities, students' misconceptions, reasoning ability, and responses to the learning approach (Cohen et al., 2017). Observation is commonly used to record classroom activities and examine how an instructional strategy is implemented in practice (Fraenkel & Wallen, 2011).

The observation sheet assessed the teacher's explanation of the learning objectives,

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presentation of the material, use of QR codes, student access to digital resources, student participation, conceptual exploration, discussion, problem solving, classroom management, and closing activities (Yunita & Irawan, 2025) . The diagnostic and reasoning ability test focused on quantities, units, measurements, accuracy, precision, measurement uncertainty, data interpretation, conceptual explanation, and conclusion drawing. Tests are commonly used to measure students' cognitive understanding and mastery of scientific concepts (Ary et al., 2019) . The student response questionnaire assessed students' interest, ease of accessing QR code-based materials, usefulness of videos and simulations, clarity of explanations, participation, conceptual understanding, reasoning ability, and overall learning experience (Widanti & Fathurrahman, 2024) . Questionnaires are suitable for collecting information about students' perceptions and attitudes toward an instructional strategy(Creswell & Creswell, 2018).

Prior to the commencement of data collection, both the learning materials and the research instruments underwent rigorous validation by two distinguished experts. The approved items were the QR code-based learning resources, lesson plans, teaching modules, tests for diagnosing and assessing reasoning skills, observation forms, and questionnaires for student responses (Sianipar et al., 2021). Expert validation examined the relevance, clarity, accuracy, language, presentation, and alignment of each instrument with the research objectives. Expert judgment is commonly used to determine the suitability of educational instruments before they are implemented (McMillan & Wergin, 2014). Each validator used a four-point rating scale to assess the instruments. The validation process ensured that the test items represented the concepts being studied and that the reasoning indicators were consistent with the research objectives (Gall et al., 2007).

The research procedure consisted of preparation, pretest administration, treatment implementation, posttest administration, and questionnaire completion. During the preparation stage, the learning materials and QR code-based digital resources were developed, and the instruments were validated (Wahyuni et al., 2019) . The pretest was administered to the control and experimental classes before the learning activities. The experimental classes then used QR code-based interactive learning during three meetings. Students used QR code-integrated worksheets to access digital explanations, videos, simulations, and exercises. The control class studied the same material through

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conventional instruction. After the learning process, all classes completed the posttest. The student response questionnaire was administered after the learning activities in the experimental classes. The data were analyzed quantitatively using descriptive statistics and inferential statistics with the assistance of SPSS version 25. The implementation of learning activities was analyzed using the following percentage formula:

$$\mathrm{P} = \frac{\text{Obtained score}}{\text{Maximum score}} \times 100\%$$

Percentage analysis is commonly used to evaluate the implementation of instructional activities (Nitko & Brookhart, 2011) . It can also be used to describe educational evaluation results and learning implementation (Creswell, 2009) . The pretest and posttest data were analyzed to determine changes in students' misconceptions and reasoning ability. The reduction of misconceptions was determined by comparing the proportion of incorrect conceptual responses before and after the treatment. A decrease in incorrect responses indicated a reduction in misconceptions. Reasoning ability was analyzed by comparing students' pretest and posttest scores. The study looked at two connected outcomes, which were misconceptions and reasoning skills, so they used a multivariate analysis of variance to check how the learning treatment affected both of these things at the same time (Putri et al., 2023). Manova was used to check if there was a significant difference between the control group and the experimental group in terms of the combination of QR code-based interactive learning and the two dependent variables. Separate univariate analyses were conducted after the multivariate test to identify the contribution of the treatment to each dependent variable.

Before conducting MANOVA, the data were examined through normality, homogeneity, and covariance assumptions. The Shapiro-Wilk test was conducted separately for each class because the normality assumption was examined within each group. Although the total sample consisted of 105 students, each group contained 35 students, making group-level normality testing appropriate. The Levene test was used to examine the homogeneity of variance. The significance level was set at $\alpha = 0.05$. Statistical testing with a significance level of 0.05 is commonly used to determine whether differences between groups are statistically significant (Field, 2018).

If the assumptions for parametric analysis were satisfied, MANOVA and follow-up univariate analyses were conducted. If the assumptions were not satisfied, the data were analyzed using appropriate nonparametric alternatives. The Mann-Whitney test

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can be used as a nonparametric alternative when the assumptions for parametric analysis are not fulfilled (Pallant, 2013) . The improvement in students' performance was calculated using the normalized gain formula:

$$N(g) = \frac{S_{posttest} - S_{pretest}}{S_{maximum} - S_{pretest}}$$

The N-gain analysis was used to determine the level of improvement between the pretest and posttest scores. Gain analysis is often used to check how much students' learning improves after a teaching activity (Johnson, 2014) . The interpretation of the gain results was supported by rating-scale analysis for educational data (Boone & Boone, 2012). The N-gain scores of the control class and the two experimental classes were compared using one-way analysis of variance. ANOVA was used to determine whether there were significant differences in learning improvement among the three classes (Gravetter & Wallnau, 2017). ANOVA is appropriate when the average scores of more than two groups are compared (Howell, 2010). The size of the treatment e

ffect was studied using Cohen's effect size to understand how strong the difference between the groups really is, even after considering statistical significance (Cumming, 2012) . Student responses to QR code-based interactive learning were analyzed descriptively using the following formula:

$$P = \frac{\text{Total questionnaire score}}{\text{Maximum questionnaire score}} \times 100\%$$

The percentage results were interpreted using predetermined rating-scale criteria. Descriptive percentage analysis is commonly used to interpret students' perceptions and attitudes toward a learning strategy (Johnson, 2014).

RESULTS AND DISCUSSION

The implementation of QR code-based interactive learning was evaluated during three learning meetings. The observation results are presented in Table 1.

Table 1. Implementation of QR Code-Based Interactive Learning

Meeting	Implementation Percentage (%)	Category
1	84.25	Very Good
2	88.63	Very Good
3	91.14	Very Good

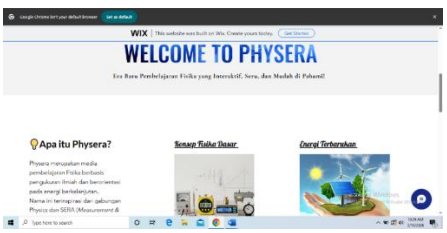
Table 1 shows that the implementation percentage increased from 84.25% in the

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first meeting to 88.63% in the second meeting and 91.14% in the third meeting. These results indicate that the learning activities were implemented consistently, with an improvement in the observed implementation score across meetings. The increasing percentages suggest that the use of QR code-based materials became increasingly integrated into classroom activities. Research on the use of technology in physics education has discussed the potential of digital tools to support physics learning (Faresta et al., 2024) . Physics learning media that integrate Google Sites with QR codes also illustrate how printed or conventional learning activities can be connected to digital resources (Prihatiningtyas et al., 2022). However, the implementation percentages in the present study describe the observed learning process; they do not, by themselves, establish the effect of the intervention on students' reasoning or misconceptions.

The learning materials combined printed worksheets with QR codes that directed students to supplementary explanations, videos, simulations, and problem-solving activities. This arrangement enabled students to access additional learning resources while working through the physics tasks. Previous studies have examined the integration of QR codes into physics learning modules and their use in textbooks to provide access to augmented-reality resources (AlNajdi, 2022; Anggraeni et al., 2022). These studies offer useful background that helps link printed materials to digital learning content. In this study, the QR codes served as a way to access extra materials, but they weren't used as a separate learning tool on their own, apart from the worksheets and classroom activities.

Figure 1. QR code used in the physics learning materials





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Figure 2. Display of QR code-based learning content, Quantities and Units



Figure 3. Virtual Experiment on the Application of Vernier Calipers and Interactive Matching Game on Physical Quantities and Their Units

Figures 1 and 2 illustrate the integration of QR codes into printed physics learning materials and the display of the digital learning content accessed through the QR codes. The digital resources provide supplementary explanations, instructional videos, simulations, and problem-solving activities to support students' exploration of physics concepts. As shown in Figures 3, the learning content covers the introduction to physical quantities and units, virtual experiments using vernier calipers, interactive matching games on physical quantities and their units, and measurement and measurement uncertainty. These activities provide students with opportunities to examine concepts, relate physical quantities to their units, interpret measurement procedures, and evaluate their understanding through interactive tasks. The implementation results showed that the learning activities were conducted consistently, with observation percentages increasing from 84.25% in the first meeting to 91.14% in the third meeting. Students also provided positive responses to the learning approach, with an overall average response of 83.75%. These findings suggest that integrating QR codes into printed learning materials provided students with accessible opportunities to explore physics concepts through additional digital resources (Ramaila, 2024) . This result is consistent with research reporting the use of QR code-supported augmented-reality resources in student textbooks to support learning performance (AlNajdi, 2022). Similarly, an integrated QR code physics module has been reported to increase students' learning interest and digital literacy (Anggraeni et al., 2022) . Physics learning media developed through Google Sites integrated with QR codes have also achieved positive feasibility and student response results (Prihatiningtyas et al., 2022) . These findings support the potential of QR code integration to facilitate access to digital learning resources and encourage students' engagement in physics learning.

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The findings of the present study are therefore generally consistent with previous research demonstrating the benefits of integrating digital resources into instructional materials (Novita & Jumadi, 2022) . However, differences in research objectives and instructional contexts should be considered when interpreting these similarities. Previous studies have focused on QR code-supported augmented reality and student performance, students' learning interest and digital literacy through an integrated physics module, and the feasibility of learning media and students' responses (AlNajdi, 2022; Anggraeni et al., 2022; Prihatiningtyas et al., 2022). In this study, QR codes were used to connect printed worksheets with supplementary explanations, instructional videos, virtual experiments, interactive matching games, and activities related to measurement and measurement uncertainty. The learning activities were designed to provide opportunities for students to analyze measurement information, identify relationships between physical quantities and units, explain their answers, and draw conclusions based on scientific concepts. The results indicate that this integration was accompanied by positive student responses and improvements in reasoning test scores (Ramadhan & Inayati, 2024). Nevertheless, the current research design does not isolate the contribution of individual digital components, such as videos, simulations, or interactive games, from the overall instructional approach. Therefore, the observed improvements should be interpreted in relation to the integrated learning activities rather than attributed exclusively to the use of QR codes or any single digital resource (Karlina Muzianti et al., 2024) . Before comparing students' scores, normality and homogeneity tests were examined. The results are presented in Table 2.

Table 2. Normality and Homogeneity Test Results

Test	Class/Test	Statistic	Sig.	Decision
Normality	X-7 Pretest	Shapiro-Wilk	0.087	Normal
	X-7 Posttest	Shapiro-Wilk	0.215	Normal
	X-10 Pretest	Shapiro-Wilk	0.093	Normal
	X-10 Posttest	Shapiro-Wilk	0.178	Normal
	X-12 Pretest	Shapiro-Wilk	0.101	Normal
	X-12 Posttest	Shapiro-Wilk	0.256	Normal
Homogeneity	Pretest	Levene	0.072	Homogeneous
	Posttest	Levene	0.064	Homogeneous

All Shapiro-Wilk significance values were greater than 0.05, and both Levene test significance values were also greater than 0.05. Thus, the reported tests did not indicate

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a significant departure from normality or homogeneity of variance at the 0.05 significance level. These findings support proceeding with the planned parametric analyses, subject to the other assumptions of each test. Statistical assumptions should be evaluated in relation to the analysis being conducted and the structure of the data (Field, 2018) . The results in Table 2 should therefore be interpreted as evidence concerning these specific assumptions, not as proof that all possible assumptions have been satisfied. The pretest and posttest scores were then compared within each class using paired-samples t-tests. The results are presented in Table 3.

Table 3. Paired-Samples t-Test Results

Class	Test Pair	Sig. (2-tailed)	Decision	Interpretation
X-7	Pretest-Posttest	<.001	Reject H_0	Significant difference
X-10	Pretest-Posttest	<.001	Reject H_0	Significant difference
X-12	Pretest-Posttest	<.001	Reject H_0	Significant difference

The paired-samples t-test results presented in Table 3 show statistically significant differences between pretest and posttest scores in all three classes ($p < .001$). This indicates that students' scores improved significantly after the learning activities in each class. However, the magnitude of improvement differed across classes. As shown in Figure 3, the mean score in class X-7 increased from 63.45 to 72.31, whereas the scores in classes X-10 and X-12 increased from 65.22 to 83.47 and from 64.18 to 81.56, respectively. The N-gain results further showed a low improvement in class X-7 (0.29), compared with moderate improvements in classes X-10 (0.53) and X-12 (0.49). These differences suggest that although all classes demonstrated significant score improvements, the increases observed in the experimental classes were greater than those in the control class.

This finding is consistent with previous studies reporting improvements in students' cognitive abilities following the implementation of technology-supported or interactive physics learning. Blended learning supported by Edmodo has been reported to improve high school students' critical thinking skills, with high N-gain results in the participating classes (Amri et al., 2025) . Similarly, a computer-assisted recitation program has been associated with significant improvement in students' conceptual understanding of static fluids, with an N-gain of 0.46 (Taqwa et al., 2022). Lately, there have been big improvements in physics learning for both the experimental and control

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groups before and after the test.However, the experimental group had a bigger increase in average scores and a higher N-gain (N. A. Lestari & Winarto, 2022). This pattern is comparable to the present findings, in which both experimental and control classes improved, but the experimental classes demonstrated greater gains.

Despite these similarities, the findings should be interpreted in light of differences in instructional approaches and measured learning outcomes across the studies. Previous studies examined critical thinking skills or conceptual understanding, whereas the present study focused on students' reasoning ability in learning physical quantities, units, and measurements (Kamilah et al., 2025). Furthermore, the important results from the paired-samples t-tests in all three classes show that there were changes within each class, but they do not by themselves prove that the QR code-based learning method was better than traditional teaching (Kartika Sari & Nabilla Qonita, 2024). The greater mean score increases and N-gain values in the experimental classes provide additional descriptive evidence of this difference. Therefore, the comparative effectiveness of the instructional approach should be interpreted based on the between-class analysis, rather than on the paired-samples t-test results alone. The mean pretest and posttest scores are shown in Figure 7.

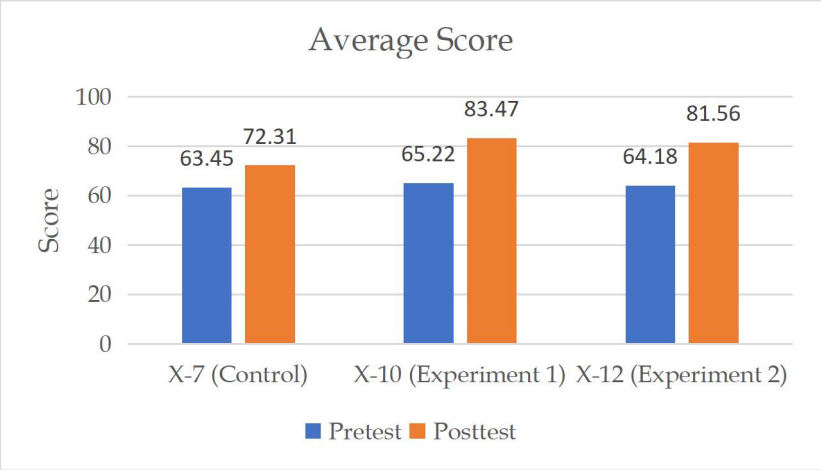


Figure 4. Comparison of average pretest and posttest scores

Figure 47 shows an increase in the average pretest and posttest scores across all three classes. In class X-7, the average score increased from 63.45 to 72.31, representing an improvement of 8.86 points. Meanwhile, class X-10 increased from 65.22 to 83.47, an improvement of 18.25 points, and class X-12 increased from 64.18 to 81.56, an improvement of 17.38 points. These results indicate that students in all classes achieved higher posttest scores than pretest scores, although the increases in the

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experimental classes were greater than that in the control class. This pattern is consistent with research reporting improvements in students' critical thinking skills following the implementation of blended physics learning supported by Edmodo (Rahman, 2024) . Similarly, computer-assisted recitation has contributed to improvements in students' conceptual understanding of static fluids (Taqwa et al., 2022). Greater improvements in physics students' critical thinking skills in the experimental class than in the control class have also been reported following the implementation of guided inquiry integrated with digital simulations (N. Lestari & Apsari, 2022) . These findings provide relevant comparisons with the present study, particularly regarding the improvement of students' cognitive abilities through technology-supported physics learning. However, the instructional approaches and learning outcomes examined in those studies differ from the present study, which integrates QR codes into printed worksheets to provide access to explanations, videos, simulations, and problem-solving activities (N. A. Lestari & Winarto, 2022) . Thus, the larger score increases observed in classes X-10 and X-12 suggest that the integrated learning approach was accompanied by greater improvements in students' reasoning scores than those observed in the control class. Nevertheless, the comparison of average scores is descriptive and does not independently establish a statistically significant difference in effectiveness between the instructional approaches. The results are presented in Table 4.

Table 4. N-Gain Results of Students' Reasoning Ability

Class	Role	N-Gain	Interpretation
X-7	Control	0.29	Low
X-10	Experimental	0.53	Moderate
X-12	Experimental	0.49	Moderate

Table 4 shows that the control class (X-7) obtained an N-gain value of 0.29, which falls into the low category, whereas the experimental classes X-10 and X-12 obtained values of 0.53 and 0.49, respectively, both categorized as moderate. These results indicate that the experimental classes achieved greater normalized gains in students' reasoning ability than the control class. A comparable pattern was reported in research on interactive PBL-based e-worksheets, in which students in the experimental class achieved a higher N-gain (0.593) than those in the control class (0.329) when developing critical thinking skills in physics (Goyal et al., 2016) . Similarly, guided

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inquiry integrated with digital simulations has been reported to produce an N-gain of 0.68 in the experimental class, compared with 0.39 in the control class (Firdausi, 2025). Higher N-gain in the experimental class (63.51%) than in the control class (55.77%) has also been reported in research implementing differentiated STEAM learning on physics measurement concepts to develop students' critical reasoning (Rosady Putri et al., 2025). These findings are consistent with the present results, as all three studies reported greater improvements in the experimental groups than in their respective control groups.

Despite this similarity, the studies employed different instructional approaches and examined different learning outcomes. Previous research focused on critical thinking through PBL-based e-worksheets, critical thinking through guided inquiry supported by digital simulations, and critical reasoning through differentiated STEAM learning in the context of physics measurement (Duterte, 2024) . The present study differs by integrating QR codes into printed physics worksheets to connect students with supplementary explanations, videos, simulations, and problem-solving activities. The moderate N-gain values in the experimental classes suggest that this integrated approach was accompanied by a greater improvement in reasoning ability than conventional instruction. However, these N-gain values provide descriptive evidence of improvement and do not independently establish statistical differences between the classes or identify the specific contribution of each digital learning component (Crompton & Burke, 2018).

The reasoning indicators were also examined descriptively. The highest reported percentage was for drawing conclusions, at 85.20%, followed by providing further explanations, at 80.32%. These results suggest that students performed comparatively well on these two reported indicators. Research has examined scientific reasoning ability among high school students in physics learning, highlighting the relevance of reasoning as an outcome in physics education (Dinata et al., 2025). Digital-technology-based teaching materials have also been investigated in relation to critical thinking in physics (Lintangesukmanjaya et al., 2025) . These studies offer context for examining reasoning-related outcomes in technology-supported learning. Nevertheless, because the present percentages are indicator-level results, they should not be interpreted as proof that every component of reasoning improved equally or that misconceptions were reduced. Differences in N-gain among the three classes were examined using a one-way

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analysis of variance (ANOVA). The reported results are presented in Table 5.

Table 5. One-Way ANOVA Results of N-Gain Scores

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.182	2	0.091	18.74	0.001
Within Groups	0.402	102	0.004		
Total	**0.584**	**104**			

The one-way ANOVA results presented in Table 5 indicate a statistically significant difference in mean N-gain scores among the three classes, provided that the reported statistical values are confirmed against the original software output. The significance value of 0.001 is below the 0.05 threshold, suggesting that the mean N-gain scores were not equal across all classes. However, this overall result does not identify which specific classes differed significantly from one another. Therefore, a post-hoc test is required to determine the pairwise differences among classes. This distinction is important because statistical significance in an omnibus ANOVA indicates an overall group difference, whereas subsequent comparisons are needed to establish the location of those differences (Antonio & Prudente, 2023). Quantitative research reports should provide complete statistical information to support accurate interpretation, while effect sizes should be reported alongside significance tests (Dewi, 2023; Lakens, 2013). Accordingly, the ANOVA result should be interpreted together with the descriptive N-gain values and, where appropriate, the results of post-hoc comparisons.

The numerical values reported in Table 5 require verification against the original statistical output before the results can be interpreted conclusively. Based on the reported between-groups mean square of 0.091 and within-groups sum of squares of 0.402 with 102 degrees of freedom, the within-groups mean square is approximately 0.00394. Consequently, the calculated F-statistic is approximately 23.09 (0.091/0.00394), rather than the reported value of 18.74. This discrepancy suggests that at least one of the reported values in Table 5 may have been transcribed incorrectly or derived from a different analysis output. Statistical results should be reported accurately and completely, including the test statistic, degrees of freedom, and significance value (Cumming et al., 2012). Similarly, effect-size calculations and statistical interpretations depend on the accuracy of the underlying statistical information (Lakens, 2013).

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Therefore, the sum of squares, degrees of freedom, mean squares, F-statistic, and significance value must be checked against the original software output. Until this verification is completed, the reported ANOVA result should not be used as definitive evidence of differences in N-gain among the three classes (Norris et al., 2015).

The reported effect-size value of 1.12 requires further clarification regarding the statistical measure and calculation method used. The interpretation of an effect size depends on the specific index applied, such as Cohen's d or eta squared, because each measure has a different calculation procedure and interpretation (Norris et al., 2015). Therefore, the value of 1.12 should not be interpreted as indicating a strong effect until its formula, input values, and corresponding statistical measure have been verified. Effect sizes provide information about the magnitude of an observed difference and complement statistical significance testing (Lakens, 2013). Effect sizes and confidence intervals also provide a more informative basis for interpreting research findings than significance values alone (Cumming et al., 2012). Complete reporting of effect-size estimates and their associated uncertainty facilitates meaningful interpretation and comparison across studies (Norris et al., 2015). Besides looking at the test results, the students' responses to the QR code-based interactive learning method were checked in three areas: the learning model, the QR code as a learning tool, and their reasoning and understanding of concepts. The average response percentages for each aspect are presented in Table 6.

Table 6. Summary of Student Responses to QR Code-Based Interactive Learning

Aspect	**Number of Items**	**Mean Response (%)**
Learning Model	4	82.28
QR Code Learning Media	4	85.11
Reasoning and Conceptual Understanding	7	83.81
Overall Average	**15**	**83.75**

As shown in Table 6, the overall average response was 83.75%. Among the three aspects, QR code learning media received the highest average percentage, at 85.11%, followed by reasoning and conceptual understanding at 83.81% and the learning model at 82.28%. These findings indicate generally positive student perceptions of the learning approach. The questionnaire results describe students' reported experiences and should be distinguished from the test results, which measure performance. Previous research

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has investigated physics learning media that integrated Google Sites with QR codes, providing a relevant comparison for the use of QR-linked resources (Prihatiningtyas et al., 2022) . Student problem-solving in relation to a case-based learning e-module has also been examined, illustrating the relevance of evaluating students' experiences with digitally supported instructional materials (Setiani et al., 2021) . The present questionnaire results, however, do not establish a causal relationship between students' positive responses and their test-score improvement.

The item-level responses also provide information about the aspects students evaluated most and least positively. The highest individual item score was 85.95% for the statement that QR codes helped students access additional explanations or learning resources. The lowest was 80.99% for the statement that the activities encouraged active participation in class. Although both percentages are above 80%, the difference suggests that students rated access to supplementary resources more positively than active participation. This distinction is important because making digital materials accessible does not automatically ensure that students engage in discussion or reasoning activities (Mayer, 2024) . Multimedia learning emphasizes the role of learners' cognitive processing, while digital learning materials can be designed to support students' critical thinking (Dewi, 2023; Mayer, 2024) . These works offer a theoretical and instructional context for interpreting student responses, but they do not independently validate the specific response pattern observed in this study.

Taken together, the implementation observations, pretest and posttest comparisons, N-gain results, and student questionnaire responses provide complementary evidence regarding the implementation of QR code-based interactive learning. The implementation percentages increased across the three meetings, from 84.25% in the first meeting to 88.63% in the second and 91.14% in the third. The mean test scores also increased in all three classes, while the experimental classes achieved higher N-gain values (0.53 and 0.49) than the control class (0.29). In addition, students gave positive responses to the learning approach, with an overall average of 83.75%. These findings are consistent with research reporting greater improvements in critical thinking skills among students using interactive PBL-based e-worksheets than among those receiving conventional instruction (Sinuraya et al., 2025) . A similar pattern was reported in research using guided inquiry supported by digital simulations, which resulted in higher

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learning gains in the experimental class (Sihombing & Yohandri, 2025) . Greater improvements in critical reasoning through differentiated STEAM learning in physics measurement have also been reported (Rosady Putri et al., 2025) . Although these studies employed different instructional approaches, their findings support the potential of interactive and technology-supported learning to improve students' cognitive abilities. In the present study, the results indicate that QR code integration was implemented consistently and was accompanied by improvements in test performance and positive student perceptions. Nevertheless, the reported ANOVA results require verification before they can be used to support conclusions about statistically significant differences among classes.

The title and objectives of this study also refer to addressing students' misconceptions. However, this outcome needs to be distinguished from improvements in reasoning ability and students' perceptions of the learning approach. Although the research design included the collection of diagnostic test data, the results presented in this study do not provide numerical pretest and posttest misconception rates, changes in misconception categories, or a corresponding statistical analysis (Widanti & Fathurrahman, 2024). Therefore, the available findings are insufficient to establish that students' misconceptions were reduced. Previous studies demonstrate the importance of examining misconception data directly. A reduction in students' misconceptions about Newton's laws following the implementation of cognitive conflict-based worksheets has been reported using a five-tier diagnostic test to compare students' conceptions before and after instruction (Azahra & Wasis, 2024) . Similarly, a decrease in students' misconceptions about energy concepts after using handouts and worksheets based on Posner's conceptual change theory has been reported (Kartika Sari & Nabilla Qonita, 2024). A decrease in physics students' misconceptions about Newton's laws, from 53% before treatment to 36% after the implementation of investigation-based group inquiry worksheets, has also been reported (Sinuraya et al., 2025). These findings demonstrate that claims about misconception reduction need to be supported by diagnostic evidence obtained before and after instruction. To know if the QR code-based learning method helped reduce students' misunderstandings, we need to share the diagnostic test results, the rules used to classify the mistakes, and the statistical comparisons. Without these data, the present study should limit its conclusions to improvements in reasoning test

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scores and students' responses to the learning activities (Ramadhan & Inayati, 2024).

CONCLUSION

QR code-based interactive learning was effectively implemented in physics learning for Grade X students at SMA Negeri 1 Cerme. The learning approach produced greater improvement in students' reasoning ability than conventional instruction, particularly in explaining measurement concepts and drawing conclusions from physics information. Students also responded positively because the QR codes provided accessible digital explanations, visual materials, simulations, and contextual exercises. These results show that using QR codes for interactive learning can serve as another way to help students explore and think about concepts related to quantities, units, and measurements. Future studies should involve a larger number of schools, longer treatment periods, and more diverse student characteristics. More studies should look at students' wrong ideas on their own and use MANOVA with data from each student to check how using QR codes in learning affects both their misunderstandings and their ability to reason. The learning media can also be developed by integrating simulations, virtual laboratories, digital quizzes, or augmented reality to support more complex physics concepts.

DECLARATION:

Phenomenon: Jurnal Pendidikan MIPA was selected as the target journal for the publication of our paper because it strives to promote the implementation of high-quality mathematics and science education at all educational levels—an objective that aligns with the vision and scope of this internationally reputable journal. We confirm that all authors have approved the manuscript for publication in your journal.

Availability of Data and Materials: The data supporting the study was classified according to the institutions' authorities; therefore, the participants only agreed to participate in the study based on anonymity, and a confidentiality agreement was reached. The data can therefore not be divulged to any third party without official permission granted from the institutions which can either be accepted or declined.

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interpretation, and scholarly conclusions were developed and verified by the authors, who take full responsibility for the content of the manuscript.

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