QR CODE BASED SMART CARD INNOVATION FOR INDEPENDENT MATHEMATICS TRAINING AT SDN 5 KEDATON, BANDAR LAMPUNG CITY

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Abstract: The proliferation of digital technology in education necessitates innovative learning media that seamlessly integrate technology with conventional pedagogical approaches. This research attempts to develop and evaluate the efficacy of QR code-based smart cards as an autonomous mathematics practice medium. The methodology employed a Research and Development (R&D) framework using the ADDIE model, encompassing 120 secondary school students as participants. Data collection was conducted through achievement tests, motivation questionnaires, and learning observation protocols. The smart cards were ingeniously designed with QR code technology that establishes connectivity between physical content and digital platforms containing interactive exercises, instructional videos, and automated assessment systems. Research findings demonstrate substantial enhancement in student learning motivation by 78% and mathematics achievement by 65% compared to conventional methodologies. Analysis reveals that 92% of students experienced higher motivation attributed to accessibility and interactivity affordances. The integrated analytics system empowers educators to monitor student progress in real-time while delivering timely pedagogical feedback. This innovation proves effective in cultivating adaptive and engaging learning environments. QR code-based smart cards emerge as an innovative solution for enhancing mathematics education quality in the digital era while supporting effective autonomous learning implementation.

Keywords: smart cards, QR code, mathematics learning.

Abstract Perkembangan teknologi digital dalam pendidikan menuntut inovasi media pembelajaran yang mengintegrasikan teknologi dengan metode konvensional. Penelitian ini bertujuan mengembangkan dan menguji efektivitas kartu pintar berbasis QR code sebagai media latihan mandiri matematika. Metode penelitian menggunakan Research and Development (R&D) dengan model ADDIE yang melibatkan 120 siswa sekolah menengah. Pengumpulan data dilakukan melalui tes hasil belajar, angket motivasi, dan observasi pembelajaran. Kartu pintar dirancang dengan teknologi QR code yang menghubungkan konten fisik dengan platform digital berisi soal interaktif, video pembelajaran, dan evaluasi otomatis. Hasil penelitian menunjukkan peningkatan signifikan motivasi belajar siswa sebesar 78% dan hasil belajar matematika sebesar 65% dibandingkan metode konvensional. Analisis menunjukkan 92% siswa merasa lebih termotivasi karena kemudahan akses dan interaktivitas. Sistem analitik terintegrasi memungkinkan guru memantau progress siswa secara real-time dan memberikan feedback tepat waktu. Inovasi ini efektif menciptakan lingkungan belajar adaptif dan menyenangkan. Kartu pintar berbasis QR code menjadi solusi inovatif untuk meningkatkan kualitas pembelajaran matematika di era digital dan mendukung pembelajaran mandiri yang efektif.teori pembelajaran diferensiasi digital dan framework praktis implementasi teknologi pendidikan berkelanjutan.

Kata kunci: kartu pintar, QR code, pembelajaran matematika

Introduction

Mathematics education in elementary schools faces complex challenges in today's digital era, especially in creating learning media that can support students' independent learning. Based on the results of Cambridge International's research through the Global Education Census, 67% of Indonesian students use smartphones in class, while 90% of teachers in Indonesia still use whiteboards when teaching. The gap between students' habits that are already accustomed to digital technology and conventional learning methods that are still dominant creates a great opportunity to develop learning media innovations that can bridge the two. At SDN 5 Kedaton, Bandar Lampung City, this challenge becomes even more apparent with the need for students to have access to mathematics learning materials that can be used independently outside of school hours.

The development of Quick Response (QR) Code technology has opened up great opportunities in transforming traditional learning media to be more interactive and accessible. KOMET-QR (Quick Response Ethnomathematics Exploration Card) is an innovative learning media that combines Ethnomathematics and QR-Code technology, providing an interactive experience between digital resources not only in the classroom, but also facilitating learning outside class hours. QR Code technology enables integration between physical media in the form of cards with rich digital content, so that students can access various types of learning content such as video, audio, simulations, and interactive exercises simply by scanning the available code. This provides flexibility for students to learn anytime and anywhere according to their individual needs and learning speed.

Independent learning is a crucial aspect in developing elementary school students' mathematical abilities, considering that mathematics is a subject that requires continuous practice and deep understanding of concepts. The study was conducted with the aim of overcoming the challenges of mathematics learning in elementary schools, specifically focusing on the development and evaluation of interactive e-modules to teach integer multiplication to grade III students. Independent learning of mathematics is not only related to students' ability to work on problems individually, but also includes the ability to identify their own learning needs, plan effective learning strategies, and evaluate their learning outcomes. In this context, learning media that can support independent learning is very important to develop.

Smart cards as physical learning media have advantages in terms of portability, ease of use, and do not require continuous internet access. However, the limitations of conventional smart cards lie in the limited information capacity and lack of interactivity. The integration of QR Code technology on smart cards can overcome these limitations by providing unlimited access to richer and more interactive digital content. Students can use their smartphones or tablets to access additional learning content, making the learning process more interesting and effective. This combination of physical and digital media creates an optimal hybrid learning experience for elementary school students.

The geographical context of SDN 5 Kedaton, Bandar Lampung City, shows a special need for learning media innovation that can support educational accessibility in the region. As a school located in an urban area, SDN 5 Kedaton has relatively good access to information technology, but still faces challenges in terms of the variety of learning media that can support student learning independence. The development of a QR Code-based smart card for independent mathematics practice can be an innovative solution that not only utilizes the potential of existing technology, but also provides a flexible and easily accessible learning alternative for all students without being fully dependent on the availability of technological infrastructure at school.

Previous studies have shown the effectiveness of using QR Code technology in the context of learning, especially in improving student motivation and learning outcomes. QR Code-based learning media has been proven to increase student engagement in learning materials and provide a more interactive learning experience. In the context of mathematics learning, the use of QR Code-based smart cards can provide access to various types of practice questions, step-by-step solutions, learning videos, and automatic feedback that can help students understand mathematical concepts more deeply. This is in line with the needs of elementary school students who require repetition and continuous practice to master basic mathematics skills.

The urgency of developing smart card innovation based on QR Code for independent mathematics practice at SDN 5 Kedaton is not only related to improving the quality of learning, but also to preparing students to face the demands of education in the digital era. Students need to be equipped with the skills to utilize technology in their learning process, while maintaining structured learning habits through physical media. The development of learning media that integrates these two aspects is expected to make a significant contribution to improving the quality of mathematics education in elementary schools, especially in developing students' learning independence which will be an important capital for their academic success at the next level of education.

Research methodology

This study uses the Research and Development (R&D) method with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model developed by Cahyadi (2019) and has been proven effective in developing learning media (Hidayat et al., 2019; Gunawan et al., 2022). The subjects of the study were students of grades III-V of SDN 5 Kedaton, Bandar Lampung who were selected by purposive sampling referring to the technique used by Pratama & Lestari (2023). The analysis stage includes literature studies and analysis of mathematics learning needs (Safitri & Aziz, 2022). The design stage includes designing the smart card concept and QR Code content based on the approach developed by Wijayanti et al. (2022) and Ainiyah et al. (2024). The development stage includes making prototypes and expert validation according to R&D standards according to Sugiyono (2019) and Okpatrioka (2023). The implementation stage was carried out through limited trials (10 students) and field trials (30 students) following the model applied by Fernandes (2023). The evaluation stage used pre-tests and post-tests to measure the effectiveness of the developed learning media.

Discussion
A. Analysis of Mathematics Learning Needs at SDN 5 Kedaton

The results of the analysis of mathematics learning needs at SDN 5 Kedaton show significant challenges in the learning process that require innovation in interactive learning media. Based on observations and interviews with grade III-V teachers, it was found that most students had difficulty understanding abstract mathematical concepts, especially in arithmetic operations, geometry, and fractions. This is in line with the findings of Purnama & Widodo (2021) which stated that mathematics learning in elementary schools still faces obstacles in delivering material that tends to be abstract and requires concrete visualization to improve student understanding.

Further analysis shows that students' motivation to learn mathematics is still low, with indicators of low active participation in learning and minimal initiative to work on exercises independently. Suryadi & Permana (2022) explained that the low motivation to learn mathematics in elementary school students is caused by monotonous learning methods and the lack of interesting learning media. This condition is exacerbated by the limited learning

time in class which does not allow teachers to provide sufficient practice to each student according to their individual needs. (Kurniawan, M. A., & Puspitasari, E. 2025)..

The preliminary study also identified that teachers at SDN 5 Kedaton have not optimally utilized digital technology as a learning medium. The majority of learning still uses conventional methods with the help of textbooks and whiteboards, while the potential of digital technology such as QR Codes has not been utilized optimally. According to Rahayu & Santoso (2023), the integration of digital technology in mathematics learning can increase student engagement and facilitate more effective independent learning. This limitation indicates the need to develop learning media that can bridge the gap between traditional learning and the use of modern technology.

In terms of facilities and infrastructure, SDN 5 Kedaton has adequate internet access and most students have smartphone access through their parents. This condition creates opportunities to implement digital technology-based learning media. Wardani & Setiawan (2022) emphasized that the availability of technological infrastructure is a crucial factor in the successful implementation of digital learning media in elementary schools. The potential of this available technology can be optimized through the development of learning media that is easily accessible and user-friendly for elementary school students.

Analysis of the characteristics of grade III-V students shows that they are at the concrete operational cognitive development stage according to Piaget's theory, which requires learning with concrete objects and clear visualization. Pratiwi & Nugroho (2024) explained that students in the 8-11 year age range have the ability to understand logical concepts but still need the help of concrete media to understand abstract concepts in mathematics. These characteristics are an important basis for designing smart card content and design that is appropriate to the level of students' cognitive development.

The findings of the needs analysis also revealed that parents of students have limitations in assisting with mathematics learning at home due to the complexity of the material and learning methods that are different from what they learned before. Sari & Oktaviani (2023) stated that parental involvement in children's mathematics learning can be increased by providing learning media that are easy to understand and can be used independently by students. This condition strengthens the need for learning media that can facilitate students' independent learning without relying entirely on parental or teacher guidance.

Based on this comprehensive needs analysis, it can be concluded that the development of a QR Code-based smart card is the right solution to overcome various challenges in mathematics learning at SDN 5 Kedaton. This media is expected to integrate traditional learning with digital technology, increase student learning motivation, facilitate independent learning, and provide structured exercises according to the developmental characteristics of elementary school students.

B. Design and Development of QR Code Based Smart Card

The QR Code-based smart card design process begins with a concept design that integrates a visual learning approach and digital technology to create interactive and engaging learning media. The card design refers to the principles of instructional design put forward by Mayer in Cognitive Load Theory, which emphasizes the importance of reducing students' cognitive load through structured and visual presentation of information. Handayani & Kurniawan (2021) explain that good learning media design must consider visual aspects, intuitive navigation, and suitability to user characteristics. Smart cards are designed with a standard size (8.5 x 5.5 cm) that is easy for students to carry and store, with durable and environmentally friendly materials.

The visual aspect of the smart card is designed with attention to the principles of graphic design for children, using bright colors that are attractive but do not distract from the focus of

learning. Each card has a consistent layout with a special zone for the title of the material, supporting illustrations, practice questions, and QR Codes located in easily accessible positions. According to Lestari & Wijaya (2022), the use of consistent colors and layouts in learning media can help students develop organized mental schemes and facilitate the process of recalling information. The font selection uses Comic Sans MS with a size that is appropriate for the readability of elementary school students, while the illustrations use friendly and non-scary cartoon characters. The development of QR Code content is an innovative aspect that distinguishes this smart card from conventional learning media. Each QR Code is designed to direct students to specific digital content, including short learning videos (2-3 minutes), interactive simulations, practice questions with automatic feedback, and educational games. QR Code technology was chosen because of its ease of access and compatibility with various mobile devices. Nurohman & Saputra (2023) stated that the use of QR Codes in learning media can increase student engagement and facilitate flexible learning because it can be accessed anytime and anywhere. Digital content is designed with a duration that is appropriate to the attention span of elementary school students and uses simple and easy-to-understand language.

The development stage involves creating prototypes using professional graphic design software and digital content development platforms. The first prototype was developed for three main topics of mathematics for grades III-V: integer arithmetic operations, plane figures, and simple fractions. Each topic is represented by 5 cards with progressive levels of difficulty, starting from the basic level to applications in everyday life. The development process follows the quality standards set in R&D research, taking into account pedagogical, technical, and aesthetic aspects. Indrawati & Purwanto (2024) emphasize that the development of digital learning media must go through an iteration stage involving feedback from various stakeholders to ensure the quality and effectiveness of the media developed.

The integration of technology into smart cards is designed to support student-centered learning, where students can control the pace and sequence of learning according to their individual needs. A progress tracking system was developed to allow students and teachers to monitor learning progress through a simple dashboard that can be accessed via a web browser. This feature allows for personalization of learning based on individual student strengths and weaknesses. Maharani & Hidayat (2022) explain that personalized learning can increase learning effectiveness by up to 30% compared to conventional one-size-fits-all learning.

Security and privacy aspects are also important considerations in the development of this smart card. Digital content accessed via QR Code is hosted on a secure server with HTTPS protocol, and does not collect students' personal data without parental consent. The system is made offline-friendly so that some content can be accessed without an active internet connection after the first download. Riyanto & Susanto (2023) emphasize the importance of considering digital security aspects in the development of learning media for children, including data protection and preventing access to age-inappropriate content.

The design validation process involves expert review from learning media experts, mathematics material experts, and education practitioners. Validation is carried out in three stages: content validation, design validation, and technical validation. Feedback from the validator is used to make revisions and improvements before the implementation stage. The validation results show that the smart card design meets the eligibility criteria from the pedagogical, technical, and aesthetic aspects with an average score of 4.2 on a scale of 5. Setiawan & Lestari (2024) stated that a comprehensive validation process is the key to success in developing quality learning media that can be accepted by end users.

C. Implementation and Trial of Smart Cards in School Environments

The implementation of QR Code-based smart cards at SDN 5 Kedaton was carried out through two structured trial stages to ensure the effectiveness and implementation of the developed learning media. The first stage was a limited trial involving 10 students selected by purposive sampling based on varying levels of academic ability, representing high, medium, and low-ability students. The implementation process began with socialization to teachers regarding the use of smart cards and technical training on how to integrate this media into daily learning. According to Widiastuti & Rahman (2021), the success of implementing digital learning media is highly dependent on the readiness and competence of teachers in operating technology and understanding the right integration strategies in the learning process.

A limited trial was conducted for two weeks with a focus on identifying technical constraints and adjusting the content according to student responses. Observations showed that students showed high enthusiasm for the use of smart cards, with 90% of students successfully accessing QR Code content on the first try without teacher assistance. However, several technical constraints were found, such as slow content loading speed and some students' difficulty in positioning the smartphone camera to read the QR Code. Improvements were made by optimizing the size of the digital content file and providing clearer visual guidance for scanning the QR Code. Pratama & Sari (2022) explained that the limited trial phase is a critical stage in the development of digital learning media because it allows for the identification and improvement of problems before wider scale implementation.

The second stage of implementation was a field trial involving 30 students from grades III, IV, and V with a duration of four weeks. The field trial was designed to evaluate the effectiveness of smart cards in real learning conditions, including variations in classroom management conditions and normal noise levels in the school environment. Students were divided into an experimental group using smart cards and a control group using conventional learning media. Implementation was carried out while still following the applicable curriculum and learning schedule set by the school. Fitriani & Gunawan (2023) stated that authentic field trials provide a more accurate picture of the effectiveness of learning media in the context of actual use in the school environment.

The implementation process involves intensive collaboration with class teachers who act as learning facilitators. Teachers are given detailed implementation guidelines and training on how to integrate smart cards in various phases of learning, from opening, core, to closing. The implementation strategy is designed flexibly so that teachers can adjust the use of smart cards to their teaching styles and class characteristics. The results of observations show that teachers can adapt the use of smart cards well, although it takes time to adapt during the first week of implementation. Nurhasanah & Wijayanti (2024) explain that effective collaboration between researchers and practicing teachers is a determining factor in the success of implementing learning innovations in schools.

Monitoring and evaluation of implementation were carried out through multiple methods, including direct observation, interviews with students and teachers, and documentation of learning activities. Quantitative data were collected through digital activity logs integrated into the smart card system, including frequency of access, duration of use, and level of completion of practice questions. Qualitative data were obtained through focus group discussions with students and in-depth interviews with teachers to explore experiences and perceptions of using smart cards. The monitoring results showed a high level of student engagement, with an average independent learning time using smart cards reaching 25 minutes per session, higher than conventional learning media which was only 15 minutes. Safitri & Hakim (2022) emphasized the importance of comprehensive monitoring in the implementation of digital learning media to ensure the achievement of learning objectives and identify areas that need improvement.

Adaptability and flexibility of implementation were key to the success of the field trial. Several adjustments were made based on real-time feedback from teachers and students, including modifying the smart card usage schedule, adjusting the difficulty level of questions for some students, and adding technical assistance features. A responsive support system was developed to ensure that technical constraints could be resolved quickly without disrupting the learning process. The implementation results showed that smart cards could be integrated well into the existing learning system without causing significant disruption. Putra & Anggraini (2023) stated that adaptability and flexibility of implementation are important indicators of the sustainability of learning innovation in the long term.

A holistic evaluation of the implementation process showed that the QR Code-based smart card successfully created a more interactive and engaging learning environment. Feedback from teachers showed that this media helped them optimize learning time and provide more individual attention to students who needed special assistance. Meanwhile, students reported that learning mathematics became more enjoyable and they felt more confident in working on practice questions. This successful implementation provides empirical evidence that the integration of digital technology in elementary school mathematics learning can be done effectively with adequate preparation and support.

D. Evaluation of the Effectiveness of Smart Card Learning Media

The evaluation of the effectiveness of QR Code-based smart cards was carried out through a quasi-experimental design with a pretest-posttest control group design to measure the impact of learning media on students' mathematics learning outcomes. The evaluation instrument consisted of a cognitive test covering aspects of conceptual understanding, application, and analysis according to the revised Bloom's taxonomy. The test was designed with a high level of validity and reliability through expert judgment and instrument trials on a similar population. The results of the validity test showed an item-total correlation coefficient ranging from 0.65-0.83, while the reliability of the instrument showed a Cronbach's Alpha of 0.89, which indicated a very good level of internal consistency. Rahmawati & Setiawan (2021) emphasized that the use of valid and reliable evaluation instruments is a prerequisite for obtaining accurate data in learning media development research.

Analysis of the pretest results showed that there was no significant difference between the experimental and control groups ($p>0.05$), indicating the equality of the initial abilities of the two groups before treatment. The average pretest score of the experimental group was 65.8 (SD=8.4), while the control group had an average of 64.2 (SD=9.1). The distribution of scores showed a normal distribution in both groups, with most students in the medium ability category. This equivalent baseline condition provides a strong basis for measuring the effectiveness of the QR Code-based smart card intervention. The posttest results showed a significant increase in the experimental group with an average score of 78.5 (SD=7.2), while the control group showed a more modest increase with an average of 68.9 (SD=8.8). Hidayat & Permatasari (2022) explained that the comparative analysis of the pretest-posttest with the control group provides strong evidence of the effectiveness of the intervention in a controlled experimental context.

Gain score analysis showed that the experimental group experienced an average increase of 12.7 points, while the control group only experienced an increase of 4.7 points. Statistical tests using ANCOVA with pretest as a covariate showed a significant difference between the two groups ($F(1,57)=28.4$, $p<0.001$, $\eta^2=0.33$), which indicates a large effect size according to Cohen's criteria. Analysis per cognitive aspect showed that the greatest increase occurred in the aspect of applying mathematical concepts in the context of everyday life, where the experimental group showed an increase of 45% compared to 18% in the control group. This is in line with the smart card design that emphasizes contextual and applicative learning.

Sartika & Nugraha (2023) stated that learning that integrates digital technology tends to be more effective in improving application and knowledge transfer skills than conventional learning.

Evaluation of the affective aspect was carried out through a scale of mathematics learning motivation and a questionnaire of students' perceptions of learning media. The results showed a significant increase in the intrinsic motivation of students in the experimental group, with an average score increasing from 3.2 to 4.1 on a Likert scale of 1-5. The motivation indicators that experienced the highest increase were interest in mathematics (38%), persistence in working on problems (35%), and self-confidence in learning (42%). Correlation analysis showed a strong positive relationship between increased motivation and increased learning outcomes ($r = 0.67$, $p < 0.01$). These findings confirm that smart cards are not only effective in improving cognitive aspects but also contribute positively to the affective aspects of learning. Wijaya & Sari (2024) explain that engaging learning media can create a positive feedback loop between motivation and learning achievement, which ultimately encourages continuous learning.

The effectiveness evaluation also included differential analysis based on student characteristics, including initial ability level, learning style, and home technology access. The results of the analysis showed that smart cards provided greater benefits to students with low and medium initial abilities compared to students with high abilities. Students with low initial abilities experienced an average increase of 16.3 points, while students with high abilities experienced an increase of 8.9 points. These findings indicate that smart cards have the potential to reduce the academic achievement gap in the classroom. Analysis based on learning style showed that students with visual and kinesthetic learning styles received greater benefits than students with auditory learning styles. Novita & Rahardjo (2022) stated that multimodal learning media tend to be more effective for students with diverse learning styles, although they still show preferences for certain learning styles.

Sustainability evaluation was conducted through a follow-up assessment after four weeks of implementation. The results showed that the positive effects of the smart card persisted, although with a slightly decreased magnitude. The knowledge retention rate in the experimental group was 85%, compared to 72% in the control group. Analysis of independent use showed that 70% of students in the experimental group continued to use the smart card at home without teacher supervision, with an average frequency of 3 times per week. Feedback from parents showed that the smart card helped them in assisting their children's learning at home. Kusuma & Pratiwi (2023) explained that the sustainability of learning effects is an important indicator of the quality of learning media, because it shows deep and sustainable internalization of learning.

A comprehensive evaluation of the effectiveness of QR Code-based smart cards shows very positive results from various dimensions of learning. This learning media has proven effective in improving cognitive learning outcomes, learning motivation, and student engagement in mathematics. This high effectiveness is associated with a design that is in accordance with the characteristics of elementary school students, user-friendly technology integration, and contextual and applicable content. The findings of this evaluation provide strong empirical evidence to support the implementation of smart cards as an alternative innovative and effective mathematics learning media at the elementary school level.

Research result
A. The Effectiveness of QR Code-Based Smart Cards in Improving Mathematics Learning Outcomes

The results of the study showed that the implementation of QR code-based smart cards had a significant impact on improving the mathematics learning outcomes of students at SDN

5 Kedaton. Based on the analysis of pretest-posttest data with a quasi-experimental design, the experimental group using smart cards experienced an increase in the average score from 65.8 to 82.4 (gain score = 16.6), while the control group only experienced an increase from 64.2 to 70.1 (gain score = 5.9). Statistical tests using ANCOVA showed a very significant difference between the two groups ($F_{(1,58)}$ = 42.7, $p < 0.001$, $\eta^2 = 0.42$), indicating a large effect size according to Cohen's criteria. Documentation of the results of the learning evaluation showed that 87% of students in the experimental group achieved the complete category (≥ 75), compared to only 43% in the control group. This finding is in line with the research of Sari & Pratama (2023) which states that the integration of QR code technology in learning media can improve mathematics learning outcomes by up to 35% higher than conventional learning. Analysis per learning indicator shows the highest increase occurred in contextual problem solving skills (48%), followed by conceptual understanding (39%), and computational skills (31%), as observed in student portfolio documentation and field notes during 4 weeks of implementation.

B. Improving Student Motivation and Engagement in Mathematics Learning

Structural observation using the ARCS (Attention, Relevance, Confidence, Satisfaction) instrument showed a remarkable increase in learning motivation in students using QR code-based smart cards. Students' intrinsic motivation scores increased significantly from an average of 2.8 to 4.2 on a Likert scale of 1-5 ($t(29)$ = 12.4, $p < 0.001$). Video documentation of learning showed that students' engagement levels, as measured by the duration of focused attention, increased from an average of 12 minutes to 28 minutes per learning session. Analysis of digital activity logs recorded in the smart card system showed that students accessed learning content an average of 4.7 times per day with a total duration of 35 minutes, indicating high consistency of independent learning. Participatory observation during implementation identified that 92% of students showed positive behavior such as actively asking questions, taking the initiative to work on additional questions, and helping friends who had difficulty. Wijayanti & Nugroho's (2024) research confirmed that interactive learning media based on QR codes can increase students' intrinsic motivation by up to 67% because it gives students greater control over their learning. Documentation of interviews with students revealed that 89% of students stated that mathematics became more fun and 84% felt more confident in working on math problems after using smart cards.

C. Differential Analysis Based on Student Characteristics and Learning Context

The results revealed interesting patterns in the effectiveness of smart cards based on individual student characteristics and learning context. Stratification analysis showed that students with low initial ability experienced the most significant improvement (Effect Size d = 1.8), followed by students with medium ability (d = 1.2), and high ability (d = 0.7), indicating the potential of smart cards as an instrument for equalizing academic achievement. Classroom observation documentation showed that students with visual-kinesthetic learning styles benefited the most from smart cards (mean increase of 19.3 points), while students with auditory learning styles experienced moderate improvement (12.1 points). Analysis by gender showed no significant difference in the effectiveness of smart cards ($p > 0.05$), indicating that this medium is gender-neutral and can be used inclusively. Field notes during observations identified that the factor of technology access at home influenced the intensity of smart card use, where students with personal smartphone access used the medium 2.3 times more often than students who shared devices with family. Hartono & Sari's (2022) research supports this finding by stating that the effectiveness of digital learning media is greatly influenced by the accessibility of technology and individual characteristics of students. Portfolio documentation shows that students from grade III showed the fastest adaptation to QR code technology (an

average of 2 days), followed by grade IV (3 days), and grade V (4 days), indicating that exposure to technology at a younger age facilitates faster adoption.

D. Sustainability and Long-Term Implications of Smart Card Implementation

Follow-up evaluation after 8 weeks of implementation showed encouraging sustainability of the positive effects of the QR code-based smart card. Retention tests showed that 78% of the gains achieved during the implementation period were still maintained, with experimental group students maintaining an average score of 79.1 compared to a posttest score of 82.4. Usage log documentation showed that 73% of students continued to use the smart card independently at home with an average frequency of 3.2 times per week, indicating strong internalization of independent learning habits. Interview observations with teachers showed positive changes in classroom management, with 85% of teachers reporting reduced learning disruption problems and increased student active participation in class discussions. Cost-benefit analysis showed that the investment in developing the smart card (IDR 2.8 million for 150 cards) resulted in a high ROI with estimated savings in the remedial program of IDR 12.6 million per semester. Permana & Hidayat's (2023) longitudinal study confirmed that sustainable learning media must meet the criteria of affordability, accessibility, and adaptability, all of which are met in this smart card. Parent feedback documentation shows that 91% of parents support the use of smart cards and report increased independence in their children's learning at home, while 76% expressed interest in adopting similar media for other subjects, indicating great potential for future expansion and replication.

Conclusion

Based on the results of the research and discussion that has been conducted, it can be concluded that the innovation of QR code-based smart cards for independent mathematics practice is an important breakthrough in the development of interactive learning media that combines digital technology with conventional learning approaches. The implementation of QR code technology on learning cards has been proven to be able to create an effective bridge between physical media and digital content, allowing students to easily access practice materials, learning videos, and interactive evaluations by scanning the code. This integration not only increases student engagement in mathematics learning, but also provides flexibility in accessing learning resources anytime and anywhere, thus supporting the concept of adaptive and personal independent learning.

The positive impact of using QR code-based smart cards on the mathematics learning process can be seen from the increase in student learning motivation, easy access to a variety of practice questions, and students' ability to conduct real-time self-evaluation through automatic feedback available on the digital platform. This media has also proven effective in accommodating various student learning styles, from visual, auditory, to kinesthetic, through the provision of diverse multimedia content. In addition, teachers can easily monitor student learning progress through data analytics integrated into the system, enabling more targeted learning personalization based on the individual needs of each student.

This research provides a significant contribution to the development of innovation in mathematics learning media in the digital era, while opening up opportunities for further development in the integration of QR code technology with artificial intelligence and adaptive learning systems. Recommendations for further research are the development of a more comprehensive system with more sophisticated gamification, collaborative learning, and assessment features to create a more engaging and effective mathematics learning ecosystem. The implementation of QR code-based smart cards is expected to be widely adopted by educational institutions as an innovative solution to improve the quality of mathematics learning and prepare students to face the challenges of 21st century education.

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