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META-ANALYSIS OF THE EFFECT SIZES OF DIGITAL LEARNING MEDIA ON STUDENT MOTIVATION

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ABSTRACT

The utilization of digital learning media in science education has experienced significant growth in line with rapid technological advancements. This study aims to systematically examine the effects of various digital learning media on students' learning motivation in science education through a meta-analytic approach. Data were analyzed from 32 relevant empirical studies published between 2017 and 2021 using Cohen's d effect size test. The meta-analysis results indicate that video-based learning media exert the greatest influence on student motivation (d = 4.27), categorized as a very large effect size. Audio-visual media show a large effect (d = 1.22), while ICT-based media and digital games exhibit medium (d = 0.50) and small (d = 0.09) effect sizes, respectively. These findings show that the effectiveness of digital learning media in enhancing students' motivation varies depending on the characteristics of the media used. This study is expected to provide valuable insights for educators and curriculum developers in selecting the most effective digital media to foster learning motivation in science education.

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INTRODUCTION

Digital learning epitomizes the transformative impact of technological advancements on contemporary education (Lay & Osman, 2018; Milyani et al., 2024). It encompasses a broad spectrum of modalities, including online learning, web-based platforms, blended learning, open learning, computer-mediated instruction, and e-learning. These modalities leverage diverse digital tools such as communication platforms (e.g., Zoom, Google Meet), learning management systems (e.g., Google Classroom, Blackboard, Edmodo), interactive games and quizzes (e.g., Kahoot!, Quizizz), and rich multimedia resources (e.g., Khan Academy, YouTube, Canva, Coursera). Empirical evidence underscores the efficacy of these approaches; for instance, research findings by Nguyen et al. (2019) demonstrated that the Web-based virtual reality significantly improved students' comprehension and outcomes (Nguyen et al., 2019) .

The deployment of digital learning media has been consistently associated with enhanced educational outcomes, particularly through increased student motivation driven by varied content delivery and interactive engagement (M. H. Lin et al., 2017; Manurung et al., 2025). This shift aligns with a broader pedagogical transition from teacher-centered to student-centered learning (Ningrum & Pranoto, 2024), facilitated by ICT-based platforms such as Pojok Digital, which provide learners with access to a wide array of applications and educational resources that foster creativity, critical thinking, and autonomous information seeking (Fidiastuti et al., 2020). Furthermore, e-learning environments that incorporate formative assessment and timely feedback mechanisms have demonstrated significant positive effects on academic achievement and motivation (Liu et al., 2020; Maatuk et al., 2021).

Recent years have witnessed the proliferation of diverse e-learning tools, including e-modules (Hasudungan Silitonga & Manurung, 2025; Istuningsih et al., 2018), digital games (Chen et al., 2019; Yang, 2012), Android virtual laboratories (Choirul et al., 2019), Quizizz (Syae Purrohman, 2021), 3D Page Flip science modules (Chien & Chu, 2018; K. Y. Lin et al., 2021), Edmodo (Putri et al., 2020; Ramadan et al., 2021; Tyasning & Fadhilah, 2020), and Quipper School Application (Sulisworo & Akhsan, 2017). These digital media have been shown to enhance motivation across multiple dimensions—Attention, Relevance, Confidence, and Satisfaction—thereby enriching the learning experience (Aslan & Duruhan, 2021; Chen et al., 2019). The widespread accessibility of these applications on smartphones and computers further democratizes educational opportunities (Ottander & Simon, 2021; Sengul, 2019). Additionally, social media platforms such as WhatsApp, Telegram, YouTube, and blogs serve as informal yet powerful learning environments, facilitating independent learning and providing abundant informational and motivational resources (Akgündüz & Akinoglu, 2017).

Despite the growing body of research on digital learning interventions, many studies report outcomes primarily in terms of normalized gain scores, often omitting comprehensive effect size metrics. Effect size measures, particularly Cohen's *d*, are critical for quantifying the magnitude and practical significance of educational interventions (Ellis, 2010). This article aims to synthesize empirical evidence on the effect sizes of digital learning media on student motivation within science education. By elucidating the differential impacts of various digital tools, this meta-analytic review seeks to inform educators and

researchers in optimizing the selection and implementation of digital learning resources to maximize motivational and educational outcomes.

METHODS

This review employed a meta-analytic approach, a rigorous and quantitative method that synthesizes findings from multiple empirical studies to estimate the overall effect size of digital learning media on students' motivation in science education. The meta-analysis followed established methodological guidelines involving formulation of research questions, systematic literature search, data extraction, effect size calculation, and synthesis of results (Munn et al., 2018).

A comprehensive literature search was conducted across multiple electronic databases to identify relevant studies published between 2017 and 2021. Keywords included "digital learning media," "motivation," and "science learning." The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework was applied to ensure transparency and reproducibility in the study selection process (Van Den Beemt et al., 2020) (see Figure 1).

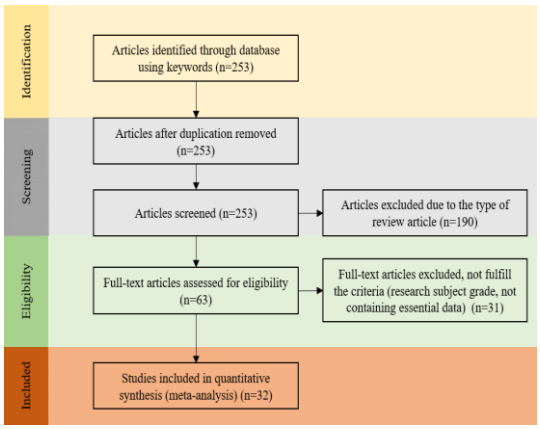

Figure 1. PRISMA flow diagram illustrating the process of article identification, screening, eligibility assessment, and inclusion for the meta-analysis.

Initially, 253 records were identified. After removing duplicates, all records underwent title and abstract screening, resulting in the exclusion of 190 articles, primarily review papers. Subsequently, 63 full-text articles were assessed for eligibility based on predefined inclusion criteria: empirical studies employing experimental designs with intervention and control groups, reporting sufficient statistical data (means, standard deviations, sample sizes), and focusing on digital learning media's impact on motivation within science education contexts (including Biology, Chemistry, Physics). Thirty-one articles were excluded due to ineligible populations, insufficient data, or methodological limitations. Ultimately, 32 studies met all criteria and were included in the meta-analysis.

From each included study, data on means, standard deviations, and sample sizes for intervention and control groups were extracted. The primary outcome measure was students' motivation to learn science. Effect sizes were calculated using Cohen's *d*, representing the standardized mean difference between groups. This metric quantifies the magnitude of the intervention effect, facilitating comparison across studies with diverse measures.

Effect sizes were synthesized using appropriate meta-analytic models. Cohen's (1988) thresholds were used to interpret effect magnitude: 0.2 (small), 0.5 (medium), 0.8 (large), with values ≥ 1.3 considered very large effects (Ellis, 2010) (see Table 1). The analysis accounted for study heterogeneity and publication bias to ensure robust conclusions.

Table 1. Effect Size Interpretation

d	Interpretation
0.0 – 0.1	No Effect
0.2 – 0.4	Small Effect
0.5 – 0.7	Medium Effect
0.8 – 1.2	Large Effect
≥ 1.3	

RESULTS AND DISCUSSION

The results of this meta-analysis are presented according to the magnitude of effect sizes, categorized following Cohen's interpretive framework. Digital learning media were classified into very large, large, medium, and small effect size categories based on their respective d values.

Table 2 demonstrates that several digital learning media produced exceptionally large effects on student motivation in science education. Most notably, video-based learning (*d* = 4.27) stands out as the most powerful intervention. This finding underscores the unique ability of video content to visualize abstract scientific concepts, making them accessible and engaging for students (Sipayung & Sipahutar, 2025). Videos can simulate phenomena that are difficult or impossible to observe directly in the classroom, such as cellular processes or chemical reactions, thereby bridging the gap between theory and real-world application (Donkin et al., 2019; Kant et al., 2017). The high effect size suggests that integrating videos into science instruction can transform passive learning into an interactive experience, fostering curiosity and sustained engagement (Octavia & Handayani, 2025).

Table 2. Digital Learning Media with Very Large Effect Size

No	Digital Learning Media	*d*
1	Video	4.27
2	Edmodo	2.89
3	Macromedia Flash 8	2.41
4	Adobe Photoshop, Camtasia studio, and PowerPoint	2.18
5	Audiovisual	2.11
6	Electronic Media (E-books)	1.99
7	3D Page Flip Science Module	1.90
8	Zoom	1.42
9	Quipper School App	1.33
10	Learning Management System	1.31

Edmodo (*d* = 2.89) and Macromedia Flash 8 (*d* = 2.41) also yielded very large effects. Edmodo's success is attributed to its flexibility in content delivery, rapid feedback, and its ability to support collaborative and problem-based learning. The platform's interactive features allow teachers to personalize learning and maintain high levels of student engagement (Putri et al., 2020). Macromedia Flash 8, with its rich animations and interactive modules, is particularly effective for complex topics like reaction rates in chemistry, where visualizing dynamic processes is crucial for understanding (Nurdin & Sulastry, 2018).

Other tools such as Adobe Photoshop, Camtasia Studio, and PowerPoint (*d* = 2.18), as well as audio-visual resources (*d* = 2.11), further highlight the importance of multimedia and interactivity. These platforms encourage students to be active participants—summarizing, presenting, and discussing content—which aligns with constructivist learning principles and supports deeper learning (Chu et al., 2019; McCauley et al., 2018).

The inclusion of e-books (*d* = 1.99) and 3D Page Flip Science Modules (*d* = 1.90) demonstrates the value of digital text and interactive modules in promoting project-based and self-directed learning. E-books, in particular, empower students to explore topics at their own pace and develop science process skills through inquiry-based activities

(Hasruddin et al., 2024; Manurung et al., 2025; Safaruddin et al., 2020).

Synchronous platforms like Zoom (*d* = 1.42), Quipper School App (*d* = 1.33), and learning management systems (*d* = 1.31) played a crucial role during the COVID-19 pandemic by enabling continuity of learning and supporting flexible, accessible instruction. These platforms facilitate real-time interaction, collaborative learning, and access to diverse resources, all of which are critical for maintaining motivation in remote or hybrid learning environments.

The consistently high effect sizes across these platforms suggest that digital media, when designed to be interactive, visually rich, and adaptable, can substantially enhance motivation in science education (Betham & Sharpe, 2013). This supports the integration of diverse digital tools as a core component of modern science curricula.

Table 3 reveals that audio-visual media (*d* = 1.22) and Android virtual laboratories (*d* = 1.18) are particularly effective in promoting student motivation. Audio-visual media's impact is rooted in its ability to present information in a multimodal format, catering to diverse learning preferences and making abstract concepts more tangible (Daineko et al., 2020; Georgiou et al., 2021; Mahfudin et al., 2021; Yang, 2012). Its simplicity and adaptability make it a practical solution for a wide range of educational contexts.

Table 3. Digital Learning Media with Large Effect Size

No	Digital Learning Media	d
1	Audio-visual	1.22
2	Android Virtual Laboratory	1.18
3	Edmodo	1.06
4	Pop-up book	1.03
5	Computer Game	0.99
6	Mobile-based Augmented Reality	0.94
7	Virtual learning environment	0.90

Android virtual laboratories offer unique, hands-on experiences that simulate real-world scientific investigations (Endang et al., 2025). These environments not only increase motivation by introducing novelty and interactivity but also help students develop critical thinking and problem-solving skills (Choirul et al., 2019; Poultsakis et al., 2021).

Other notable media include Edmodo (*d* = 1.06), pop-up books (*d* = 1.03), and computer games (*d* = 0.99). Pop-up books, with their tactile and visual appeal, engage younger learners and make science content memorable and enjoyable. (Manurung et al., 2025). Game-based learning environments foster collaboration, competition, and immediate feedback, all of which are known to enhance intrinsic motivation and persistence (Chang & Yeh, 2021; Hussein et al., 2019).

Mobile-based augmented reality (*d* = 0.94) and virtual learning environments (*d* = 0.90) introduce innovative ways to explore scientific concepts, leveraging technology to create immersive and interactive experiences. These tools are particularly effective in sustaining attention, stimulating curiosity, and providing opportunities for experiential learning (Arici et al., 2019; Mystakidis et al., 2022).

The large effect sizes associated with these tools highlight the importance of interactivity, novelty, and multimodal content in digital learning (Putri Nabila & Prastowo, 2025). Educators should consider incorporating such media to create engaging, student-centered learning environments that foster sustained motivation and deeper understanding (S. Y. Huang et al., 2020; Saritepeci, 2021).

Table 4 shows that digital games (*d* = 0.77), electronic learning (*d* = 0.76), and QR Code & Edmodo (*d* = 0.67) have moderate yet meaningful impacts on motivation. Digital games, in particular, maintain students' attention and curiosity through challenge, feedback, and reward mechanisms, which are essential for fostering intrinsic motivation (Yang, 2012). The sustained motivation observed in game-based learning environments suggests that they are well-suited for long-term engagement, especially when aligned with learning objectives.

Table 4. Digital Learning Media with Medium/Intermediate Effect Size

No	Digital Learning Media	*d*
1	Digital game	0.77
2	Electronic learning	0.76
3	QR Code & Edmodo	0.67
4	Pre-recorded instructional videos	0.64
5	Android-Base Biology Educational Game with E-Module	0.63
6	Visual media	0.60
7	Digital Escape Room	0.56
8	ICT-based media	0.50

Electronic learning platforms that incorporate assessment for learning and regular feedback help students monitor their progress, set goals, and stay motivated over time (Fang & Hsu, 2019; Stears & Gopal, 2010). The integration of QR codes with Edmodo provides a seamless way to access content and assessments, supporting flexible and efficient learning.

Pre-recorded instructional videos (*d* = 0.64) and Android-based biology games with e-modules (*d* = 0.63) support self-paced, self-directed learning. These tools allow students to revisit content as needed, catering to individual learning needs and promoting autonomy (Haryanto & Billah, 2020; Manurung et al., 2025).

Visual media (*d* = 0.60) and digital escape rooms (*d* = 0.56) leverage visual and experiential learning strategies to maintain interest and engagement. Digital escape rooms, in particular, combine problem-solving with gamification, making learning both challenging and enjoyable (Y. Huang et al., 2023).

ICT-based media (*d* = 0.50), such as Pojok Digital, expand access to information and foster creativity and critical thinking by encouraging students to explore beyond traditional classroom materials (Fidiastuti et al., 2020).

While the effect sizes are moderate, these digital tools are valuable for supporting differentiated instruction, promoting self-regulation, and maintaining engagement, especially in blended or flipped classroom models.

Table 5 indicates that certain Android-based media yielded small effect sizes (*d* = 0.40 or lower), suggesting limited impact on student motivation in specific contexts. This may be due to factors such as lack of interactivity, insufficient alignment with curricular goals, or inadequate integration into the instructional process.

Table 5. Digital Media with Small to No Effect Size

No	Digital Learning Media	*d*
1	Android	0.40
2	Digital Games (MyKimDG)	0.37
3	Quizizz	0.35
4	Social Media	0.28
5	Video games	0.26
6	Electronic Module	0.17
7	Digital games	0.09

These findings highlight that not all digital media are equally effective. The success of digital interventions depends on thoughtful design, relevance to learning objectives, and

the degree to which they engage students actively (Chai et al., 2020). Educators should critically evaluate digital tools for their pedagogical value and suitability for their specific instructional context (Yeh et al., 2021).

The overall trend observed in the data indicates that digital learning media characterized by interactivity, rich visual content, and adaptability to student needs consistently yield the greatest motivational benefits in science education. The variability in effect sizes across media types underscores the importance of aligning digital tool selection with pedagogical goals, content characteristics, and student preferences. Future research should continue to explore the contextual and design factors that mediate the effectiveness of digital learning media, with an emphasis on maximizing both engagement and learning outcomes.

CONCLUSION

This meta-analysis offers compelling evidence that digital learning media play a pivotal role in enhancing students' motivation within science education. The key finding reveals that multimedia-rich and interactive digital tools—such as video-based learning, virtual laboratories, and e-books—produce significantly larger motivational effects compared to less interactive or traditional digital formats. These results emphasize that the quality and design of digital learning media critically influence their effectiveness in engaging students and fostering sustained motivation.

Importantly, this study fills a critical gap in the literature by quantitatively synthesizing effect sizes across diverse digital learning interventions, providing educators, curriculum developers, and policymakers with clear, evidence-based guidance on which digital tools are most impactful for motivating science learners. The variability in effect sizes further highlights the necessity of aligning digital media selection with pedagogical goals, content complexity, and learner characteristics to maximize educational outcomes.

By systematically evaluating the motivational impact of various digital media, this research advances our understanding of how technology can be strategically leveraged to transform science education. It underscores the potential of well-designed digital interventions to not only enhance motivation but also support deeper conceptual understanding and active learning. As digital technologies continue to evolve, this study provides a foundational framework for future research and practice aimed at optimizing the integration of digital media to improve student engagement and achievement in science disciplines.

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