ISSN 2986-6871 (online)
Jurnal Pendidikan Dasar & Menengah
EduMedia
SK Badan Riset & Inovasi Nasional (BRIN) Nomor: 29866871/II.7.4/SK.ISSN/05/2023

Interactive Flat Panel-Based Digital Learning Media for Fostering Critical Thinking Skills of Elementary School Students in Solar System Learning

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Informasi Artikel:

Dikirim: 10-Agustus-2026
Direvisi: 26-Agustus-2026
Diterima: 10-September-2026

Dipublikasikan online:
14-September-2026

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Article DOI:
https://doi.org/10.69743/edumedia.v4i2.64

Abstract: Critical thinking is a key twenty-first-century competency that should be developed from the elementary school level, particularly in Natural and Social Science (IPAS) learning on the Solar System, which involves abstract and macroscopic concepts. This article aims to systematically examine the contribution of Interactive Flat Panel (IFP)-assisted digital learning media to enhancing elementary school students' critical thinking skills and to identify the research gap underlying the development of BUKITA (Bumi Kita dalam Tata Surya) digital media. This study employed a systematic-narrative literature review of 34 articles indexed in Scopus and other reputable databases, including Google Scholar, DOAJ, ScienceDirect, Springer, and ERIC, published between 2018 and 2026, with emphasis on the last three years. The synthesis indicates that IFP has the potential to enhance Facione's critical thinking indicators, namely interpretation, analysis, evaluation, and inference, through three-dimensional visualisation, interactive simulations, and direct manipulation of digital objects. The effectiveness of IFP is strongly influenced by the appropriateness of pedagogical design rather than technological sophistication alone. A research gap remains regarding the specific application of IFP for Solar System learning in Indonesian elementary schools. Therefore, developing BUKITA assisted by IFP offers an innovative approach to supporting students in understanding abstract astronomical concepts in a concrete and meaningful way.

Keywords: critical thinking, Interactive Flat Panel, interactive digital media, Solar System, elementary school

Abstrak: *Kemampuan berpikir kritis merupakan salah satu kompetensi abad ke-21 yang perlu dikembangkan sejak jenjang sekolah dasar, khususnya dalam pembelajaran Ilmu Pengetahuan Alam dan Sosial (IPAS) pada materi Tata Surya yang bersifat abstrak dan makroskopis. Artikel ini bertujuan untuk mengkaji secara sistematis kontribusi media pembelajaran digital interaktif berbantuan Interactive Flat Panel (IFP) terhadap peningkatan kemampuan berpikir kritis siswa sekolah dasar serta mengidentifikasi kesenjangan penelitian sebagai dasar pengembangan media digital BUKITA (Bumi Kita dalam Tata Surya). Penelitian ini menggunakan systematic-narrative literature review dengan menganalisis 34 artikel yang terindeks Scopus dan basis data bereputasi lainnya, yaitu Google Scholar, DOAJ, ScienceDirect, Springer, dan ERIC, yang diterbitkan pada 2018–2026 dengan penekanan pada tiga tahun terakhir. Hasil sintesis menunjukkan bahwa IFP berpotensi meningkatkan indikator berpikir kritis yang dikemukakan Facione, meliputi interpretasi, analisis, evaluasi, dan inferensi, melalui visualisasi tiga dimensi, simulasi interaktif, serta manipulasi objek digital secara langsung. Efektivitas IFP sangat dipengaruhi oleh kesesuaian desain pedagogis, bukan semata-mata kecanggihan teknologi. Kesenjangan penelitian ditemukan pada penggunaan IFP secara spesifik untuk pembelajaran Tata Surya di sekolah dasar Indonesia. Pengembangan BUKITA berbantuan IFP menjadi alternatif inovatif untuk membantu siswa memahami konsep astronomi secara konkret dan bermakna.*

Kata kunci: *berpikir kritis; Interactive Flat Panel; media digital interaktif; Tata Surya; sekolah dasar.*

CARA MENGUTIP:
Aliviana, R. Prahani, B.K., Widodo, W., Isbadrianingtyas, N. (2025). Interactive Flat Panel-Based Digital Learning Media for Fostering Critical Thinking Skills of Elementary School Students in Solar System Learning. *Jurnal Pendidikan Dasar & Menengah – Edumedia*, *4*(2), 127–145. DOI: https://doi.org/10.69743/edumedia.v4i2.64

1. INTRODUCTION

Education fundamentally functions as a transformative process that builds knowledge, skills, and character in learners from an early stage of schooling. Entering the demands of twenty-first-century learning, elementary school students are expected to master higher-order thinking competencies, among which critical thinking occupies a central position within global educational frameworks. Critical thinking is broadly understood as an intentional and self-regulatory cognitive process encompassing interpretation, analysis, evaluation, and inference of information encountered in daily life (Facione, 1990). This competency has increasingly been recognised as a core dimension of twenty-first-century skills alongside communication, collaboration, and creativity, and its explicit integration into national curricula has become a growing policy concern in many education systems (Herlinawati et al., 2024). Elementary school teachers are consequently expected to design learning experiences that move students beyond rote memorisation toward reasoned, evidence-based judgement. Within this broader competency landscape, science learning represents one of the most fertile yet challenging contexts for cultivating critical thinking among young learners.

Despite this policy emphasis, empirical evidence continues to show that the critical thinking performance of elementary school students in science remains unsatisfactory (Dewi et al., 2023). International assessments indicate that the scientific literacy of Indonesian students remains below the international average, reflecting persistent difficulty in applying reasoning skills to authentic scientific contexts (OECD, 2023). Scholars argue that scientific literacy in the present century must be understood not merely as content mastery but as the capacity to evaluate evidence and distinguish credible claims from misinformation, a competency that classroom instruction rarely cultivates explicitly (Osborne & Allchin, 2025). Contributing factors to this gap include instructional practices still dominated by lecturing, verbal memorisation, and minimal use of innovative learning media, which collectively constrain opportunities for students to construct scientific understanding actively (Nida et al., 2020). Comparative curriculum analyses further suggest that the operational definition of scientific literacy varies considerably across education systems, complicating efforts to translate policy aspiration into consistent classroom practice (Norambuena-Meléndez et al., 2023). These converging lines of evidence establish the first component of the research gap addressed in this review: a persistent disconnect between curricular aspiration for critical thinking and actual classroom outcomes in elementary science education.

Within the elementary science curriculum, the Solar System unit represents a particularly demanding topic because its core concepts, including planetary characteristics, celestial motion, and interplanetary distance, are inherently macroscopic and cannot be directly observed inside a classroom. Prior studies applying three-dimensional visualisation to astronomy instruction, such as a virtual reality model of the sun and moon developed for elementary e-learning (Sun et al., 2010), report that concrete representation substantially improves conceptual understanding among young learners who are still transitioning through Piaget's concrete-operational stage of cognitive development (Piaget, 1969). Given that elementary school students rely heavily on tangible, manipulable representations to construct new knowledge

(Börnert-Ringleb & Wilbert, 2018), instructional strategies for the Solar System unit that remain confined to static textbook illustrations are unlikely to support the depth of reasoning required for genuine critical thinking. Emerging design studies on three-dimensional solar system media report meaningful gains in conceptual understanding when interactivity and visual realism are combined, yet such studies rarely extend their analysis to critical thinking indicators specifically. This creates the second layer of the research gap: existing solar system media innovations tend to prioritise conceptual comprehension over the higher-order reasoning processes that critical thinking demands.

Digital technology has been reported as an effective strategy for strengthening science literacy at the elementary level, providing a foundation for more specific technological interventions such as the one discussed below (Atmojo & Wardana, 2025). A promising technological pathway for addressing this instructional challenge is the Interactive Flat Panel (IFP), a large-format touchscreen device that integrates computing, high-resolution display, and digital whiteboard functionality within a single interface. Empirical investigations of IFP implementation in mathematics learning demonstrate that the device supports the transition from concrete manipulation to symbolic abstraction through animation, simulation, and drag-and-drop virtual manipulatives (Hasanah et al. 2025). Complementary evidence from longitudinal classroom research indicates that interactive whiteboard-based formative assessment can meaningfully predict subsequent mathematics achievement, particularly when teachers design activities that exploit the device's interactive affordances rather than using it as a passive projection screen (I.-H. Chen et al., 2020). These findings collectively suggest that IFP holds considerable pedagogical potential for visualising abstract scientific phenomena, yet the majority of existing IFP research concentrates on mathematics or general classroom engagement rather than on science-specific critical thinking outcomes.

Although IFP facilities have already been installed in numerous Indonesian elementary schools, their utilisation frequently remains suboptimal because of limited availability of purpose-built digital content and a persistent tendency among teachers to deliver one-directional instruction despite the device's two-way interactive capability. This pattern mirrors a broader concern in the literature that pedagogical design, rather than technological sophistication alone, ultimately determines whether digital media translate into genuine cognitive gains. Systematic reviews of technology-enhanced collaborative inquiry similarly emphasise that the effectiveness of digital tools depends on how deliberately activity strategies are aligned with specific stages of the inquiry process (F. Chen & Chen, 2025). Consequently, a considerable gap remains between the technological availability of IFP in Indonesian classrooms and the pedagogical content required to activate its interactive potential for developing critical thinking in science learning, particularly on abstract topics such as the Solar System.

Building upon these three converging gaps, namely the underdeveloped critical thinking outcomes in elementary science, the conceptual rather than reasoning-oriented focus of existing solar system media, and the underutilised interactive capacity of IFP in Indonesian classrooms, this article undertakes a systematic-narrative literature review to synthesise empirical evidence on the use of interactive digital media assisted by Interactive Flat Panel technology for enhancing elementary students' critical thinking skills. The review specifically maps how previous studies have operationalised critical thinking indicators, what pedagogical designs have proven effective in IFP-based instruction, and where the literature falls short in addressing science content such as the Solar System. This synthesis subsequently provides the conceptual and empirical foundation for the development of the BUKITA (Bumi Kita dalam Tata Surya) interactive digital media, positioning the present study as a direct response to the identified research gap rather than a mere replication of prior technological applications.

2. LITERATURE REVIEW

2.1 Critical Thinking as a Foundational Competency in Elementary Science Education

Critical thinking has long been positioned as one of the central competencies that education systems must deliberately cultivate rather than assume will develop naturally through ordinary classroom exposure. Facione (1990) defines critical thinking as a purposeful and self-regulatory judgement process that involves interpreting, analysing, evaluating, and inferring information, as well as explaining the reasoning behind a given conclusion. This definition has become the most widely adopted theoretical foundation in critical thinking research because it offers four measurable indicators that can be operationalised into classroom instruments and learning outcomes.

The first indicator, interpretation, refers to the ability to understand and classify information or phenomena presented in various forms, such as images, diagrams, or simulations, into an organised and meaningful structure. The second indicator, analysis, refers to the ability to identify relationships between variables or elements within a phenomenon, including recognising patterns of cause and effect. The third indicator, evaluation, refers to the ability to assess the credibility and validity of a statement or piece of data before accepting it as a basis for reasoning. The fourth indicator, inference, refers to the ability to draw logical conclusions or generalisations based on evidence that has been interpreted, analysed, and evaluated.

These four indicators are not isolated abilities but form a cumulative reasoning sequence, in which interpretation and analysis generally precede evaluation and inference. This sequential characteristic becomes an important reference in the present review because it explains why several studies discussed in the following sections report stronger improvement in interpretation and analysis compared with evaluation and inference, particularly on topics that are abstract in nature and require sustained cognitive engagement, such as the Solar System.

2.2 Interactive Digital Media and the Interactive Flat Panel as a Learning Tool

Interactive digital media refers broadly to technology-based instructional tools that allow learners to manipulate, respond to, and receive immediate feedback from digital content, distinguishing it from conventional media that only present information in a one-directional manner. Within this broader category, the Interactive Flat Panel represents a large-format touchscreen device that integrates computing capability, high-resolution display, and digital whiteboard functionality into a single interface. The device allows teachers and students to write, drag, zoom, and manipulate digital objects directly on the screen, features that are considered pedagogically valuable for representing abstract or macroscopic phenomena in a concrete and observable form.

Several studies reviewed in this article indicate that the pedagogical value of the Interactive Flat Panel is closely tied to the cognitive theory of multimedia learning, which explains that the simultaneous processing of visual and verbal information through separate cognitive channels helps learners construct more meaningful mental representations (Mayer, 2024). This theoretical foundation becomes the basis for understanding why three-dimensional visualisation and direct object manipulation on the Interactive Flat Panel are consistently associated with improvement in the analysis and inference indicators, as further elaborated in the Results section.

2.3 The Solar System as an Abstract Topic in Elementary Science Curriculum

The Solar System unit occupies a distinctive position within the elementary science curriculum because its core concepts, including planetary characteristics, orbital motion, and interplanetary distance, cannot be directly observed or physically demonstrated inside a classroom. According to Piaget's theory of cognitive development, elementary school students are generally situated within the concrete-operational stage, during which reasoning still depends heavily on tangible and manipulable representations rather than purely abstract symbols (Piaget, 1969). This developmental characteristic explains why static textbook illustrations are considered insufficient for supporting deep conceptual understanding of astronomical phenomena, and why three-dimensional or interactive visualisation is repeatedly recommended in the literature as a more developmentally appropriate approach. The conceptual link between concrete-operational reasoning and the visualisation demands of astronomy education becomes an important theoretical bridge in this review, connecting the discussion of critical thinking indicators with the specific instructional challenges posed by the Solar System topic.

2.4 Positioning of the Present Review

Taken together, the three theoretical foundations discussed above, namely Facione's critical thinking framework, the pedagogical affordances of the Interactive Flat Panel, and the developmental demands of teaching an abstract astronomical topic to concrete-operational learners, form the conceptual lens applied throughout this literature review. This lens guides the subsequent identification, screening, and thematic synthesis of the 34 reviewed articles, and provides the theoretical justification for treating the four critical thinking indicators as the primary analytical categories used in the Results section.

3. RESEARCH METHOD

3.1 Research Design

This study employed a systematic-narrative literature review design, which combines the structured search and screening procedures of a systematic review with the interpretive, theme-building capacity of narrative synthesis. This hybrid design was selected because the research questions required both a transparent and reproducible search process and an integrative discussion capable of connecting findings across heterogeneous study designs, ranging from quasi-experimental research to research and development studies.

The review process followed four sequential phases, namely identification, screening, eligibility assessment, and synthesis, adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses protocol, which is widely regarded as a rigorous standard for ensuring methodological transparency in literature-based research (Moher et al., 2009). This design allows the review not only to describe the existing body of literature but also to construct an integrated argument regarding the pedagogical potential of Interactive Flat Panel-assisted media for elementary science instruction, particularly on the Solar System topic.

3.2 Data Sources and Sample of Articles

Because this study is a literature review rather than an empirical study involving human participants, the unit of analysis consists of published articles rather than individual respondents. The literature search was conducted across six databases, namely Scopus, ScienceDirect, Springer Link, DOAJ, ERIC, and Google Scholar, using combinations of the keywords critical thinking, interactive digital media, Interactive Flat Panel, elementary school, and solar system. The search was restricted primarily to publications from 2018 to 2026, with emphasis placed on articles published within the past three years in order to capture the current state of the art. The initial database search yielded 187 records. After duplicate removal and title or abstract screening for topical relevance, 96 records remained for full-text eligibility assessment. Following this assessment against the inclusion and exclusion criteria, 34 articles were retained as the final sample for detailed synthesis. The screening and selection flow is illustrated in Figure 1.

3.3 Research Instrument

The instrument used to guide data extraction in this review was a structured coding framework developed by the researcher based on the four critical thinking indicators proposed by Facione (1990), namely interpretation, analysis, evaluation, and inference. This framework functioned as the primary tool for systematically reading, classifying, and comparing the findings reported across the 34 reviewed articles. In addition to the critical thinking indicators, the coding framework also recorded the type of interactive media employed, the research design used in each study, and the key findings reported by the authors. The inclusion and exclusion criteria applied during the screening phase, presented in Table 1, served as a complementary instrument to ensure that only articles meeting the topical, methodological, and publication standards of this review were carried forward to the synthesis stage. Table 1 below is presented to give an overview of the five criteria applied consistently throughout the screening and eligibility phases.

Table 1. Inclusion and Exclusion Criteria for Literature Selection

No.	Criterion	Inclusion	Exclusion
1.	Publication type	Peer-reviewed journal article	Non-peer-reviewed sources (blog posts, opinion pieces)
2.	Publication year	2018-2026 (priority given to 2023-2026)	Published before 2018, unless a foundational theoretical work

No.	Criterion	Inclusion	Exclusion
3.	Topic relevance	Critical thinking, interactive digital media, IFP, elementary science	Topics unrelated to K-12 interactive learning media
4.	Language	English or Indonesian with an English abstract	Full text not accessible
5.	Study design	Quasi-experimental, R&D, systematic review, survey	Non-empirical commentary lacking a clear methodological basis

Table 1 shows that priority was given to studies published within the past three years to preserve currency, while a small number of theoretically foundational works, such as Piaget's theory of cognitive development and Facione's critical thinking framework, were retained regardless of publication year because of their conceptual centrality to the review.

3.4 Data Collection Technique

Data collection in this review was carried out through a documentation study technique, in which relevant articles were retrieved, read in full text, and systematically recorded rather than obtained through direct interaction with human subjects. The procedure began with the identification phase, in which keyword combinations were entered into the six databases to generate an initial pool of 187 records. This was followed by the screening phase, during which titles and abstracts were examined to remove duplicates and to exclude records that were clearly unrelated to the topic, resulting in 96 records proceeding to the eligibility phase. During the eligibility phase, the full text of each remaining article was read carefully and evaluated against the inclusion and exclusion criteria presented in Table 1.

Articles that satisfied all five criteria were retained, while those that failed to meet one or more criteria were excluded, and the reason for exclusion was recorded. This process resulted in a final set of 34 articles that were carried forward to the synthesis stage, as illustrated in the PRISMA flow diagram in Figure 1. Each retained article was then documented in a synthesis matrix recording the author and year of publication, the type of media or technology examined, the research design employed, the critical thinking indicator or indicators measured, and the key findings reported by the original authors.

3.5 Data Analysis Technique

Data analysis in this review was conducted using thematic coding combined with narrative synthesis. The 34 retained articles were first coded according to three analytical categories, namely the critical thinking indicators addressed, the type of interactive media employed, and the reported learning outcomes. This coding process allowed patterns across studies to be identified systematically rather than being described anecdotally. Once the thematic coding was completed, the findings were organised into a synthesis matrix, as presented in the Results section, to provide a comprehensive overview of the existing research landscape. Quantitative indicators reported in the original studies, such as N-Gain scores, were further categorised into high, medium, and low improvement categories to identify general patterns of effectiveness across the reviewed literature.

The narrative synthesis stage then integrated these thematic and quantitative patterns into a coherent discussion for each critical thinking indicator, connecting the findings of individual studies to the broader theoretical foundations discussed in the Literature Review section. This analytical approach enabled the review to move beyond simple description toward an integrated argument regarding the pedagogical potential of Interactive Flat Panel-assisted media, and ultimately toward identifying the specific research gap that justifies the development of the BUKITA media for Solar System instruction in Indonesian elementary schools.

4. RESULT

4.1 General Characteristics of the Reviewed Articles

The initial database search yielded 187 records, which were reduced to 96 after duplicates were removed and titles and abstracts were screened for topical relevance. Following full-text eligibility assessment against the criteria presented in Table 1, 34 articles were retained for detailed synthesis. The screening and selection flow is illustrated in Figure 1.

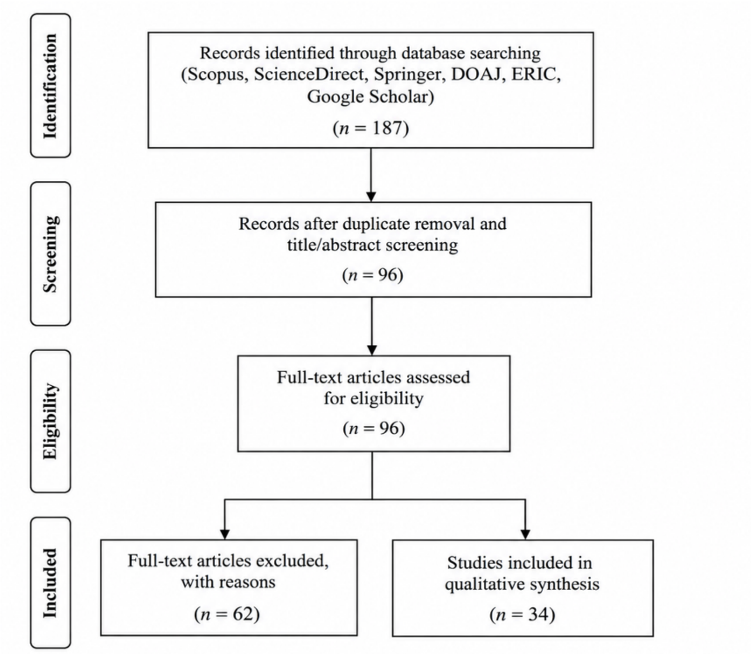

Figure 1. PRISMA flow diagram illustrating the literature identification, screening, eligibility assessment, and study inclusion process

The reviewed literature was dominated by Scopus- and DOAJ-indexed journals discussing interactive learning media at the elementary school level, with topics spanning the use of IFP, augmented reality media, interactive video, and digital simulation. The distribution of articles by research focus, media type, and the critical thinking indicators measured is presented in Table 2 to provide a comprehensive overview of the existing research landscape.

Table 2. Synthesis Matrix of Reviewed Literature on Interactive Digital Media and Critical Thinking

No.	Author(s) & Year	Media Technology	Research Design	Critical Thinking Indicator(s) Measured	Key Finding
1.	(Sulthon et al., 2025)	Augmented Reality	Research & Development (4D)	Interpretation, Analysis	N-Gain 0.51 (medium), significant improvement in scientific reasoning
2.	(Simanjuntak et al., 2022)	Inquiry-based interactive media	Quasi-experimental	Analysis, Evaluation	Interactive media-assisted inquiry outperformed conventional instruction
3.	(Lungdiansari et al., 2024)	MABER interactive multimedia	Pre-experimental (one group)	All four indicators	Significant N-Gain increase in critical thinking scores
4.	(Meryastiti et al., 2023)	Macromedia Flash e-module	Quasi-experimental	Interpretation, Inference	The interactive e-module significantly improved reasoning compared with static text
5.	(Widiyono & Ghufron, 2024)	LCD media with PjBL-STEM	True experimental	Analysis, Evaluation	LCD-based PjBL-STEM improved critical thinking, although media specificity requires refinement
6.	(Hasanah et al. 2025)	Interactive Flat Panel	Quasi-experimental	Analysis (abstraction)	IFP significantly enhanced the transition from concrete to symbolic reasoning
7.	(Aryanti & Airlanda, 2024)	STEAM interactive storybook	Research & Development	Analysis, Inference	The storybook media improved synthesis and conclusion-drawing skills
8.	(Pranata & Karyodiputro, 2026)	3D solar system media	Quasi-experimental	Conceptual understanding (a precursor to interpretation)	Experimental class N-Gain of 57.89%, moderately effective
9.	(I.-H. Chen et al., 2020)	Interactive Whiteboard	Longitudinal quantitative	Analytical/mathematical reasoning	Long-term IWB-based formative assessment predicted achievement gains
10.	(F. Chen & Chen, 2025)	Various technology-enhanced tools	Systematic review (58 studies)	Argumentation, inquiry reasoning	Effectiveness depends on the alignment between tools and inquiry-stage design

Of the 34 articles retained for synthesis, ten studies are presented in detail in Table 2. These ten were selected as a representative sample that captures variation in media type, including IFP, augmented reality, interactive whiteboards, and interactive multimedia, and in research design, including quasi-experimental, research and development, and systematic review studies. The remaining 24 articles are summarised thematically within the narrative synthesis in Sections 4.2, 4.3, and the Discussion, where their findings are integrated according to the critical thinking indicator each study addressed. This approach was taken to avoid repeating similar findings in tabular form. Each of the 24 articles is nonetheless incorporated into the overall synthesis through its contribution to the indicator-based discussion.

Table 2 shows that, among the ten representative articles synthesised, the majority employed a quasi-experimental design with a pretest-posttest control group model, and almost all reported significant improvement in at least two of Facione's four critical thinking indicators. A notable pattern is that media based on three-dimensional visualisation and touch manipulation tend to produce a stronger effect on the analysis and inference indicators than conventional video or printed interactive media. The finding reported in the tenth row also confirms that the effectiveness of technology depends on the alignment between activity strategy and the targeted reasoning stage, rather than on device sophistication alone.

4.2 Patterns of IFP Utilisation and Emerging Critical Thinking Indicators

A closer examination of the ten studies that explicitly addressed IFP or similar devices (interactive whiteboards, multitouch tables) shows that all four of Facione's critical thinking indicators, namely interpretation, analysis, evaluation, and inference, repeatedly emerged as measured dependent variables. For the interpretation indicator, these studies generally reported that students were better able to classify visual information presented on the touchscreen in a more organised manner compared with control groups taught using textbooks. For the analysis indicator, the use of dynamic simulation features and three-dimensional object manipulation was consistently associated with improved student ability to examine cause-and-effect relationships between variables, such as the relationship between a planet's position and the length of its revolution period. The distribution of N-Gain scores across the quasi-experimental studies reviewed is presented in Table 3.

Table 3. Distribution of N-Gain Scores across Quasi-Experimental Studies on Interactive Digital Media

N-Gain Category	Score Range	Number of Studies	Percentage
High	> 0.70	6	26%
Medium	0.30-0.70	14	61%
Low	< 0.30	3	13%

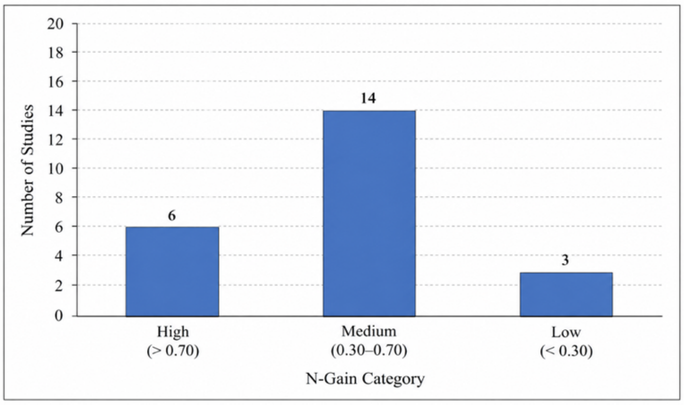

Figure 2. Distribution of N-Gain scores across quasi-experimental studies on interactive digital media

As shown in Table 3, the majority of studies (61%) reported a medium improvement category, while only a small proportion (13%) reported a low category. This distribution pattern indicates that interactive digital media, including IFP, are generally effective in improving critical thinking skills, but their degree of effectiveness varies considerably depending on intervention duration, pedagogical design quality, and the appropriateness of content for the subject matter taught. This variation underpins the argument that the development of the BUKITA media assisted by IFP needs to be designed specifically for the Solar System topic, rather than adapting generic content that is not tailored to the visualisation demands of astronomy.

The variation in N-Gain category shown in Table 3 can be partly explained by differences in study characteristics. Studies with longer intervention durations, generally four weeks or more, are more frequently found in the high N-Gain category. Shorter interventions, such as single-session trials, are more often associated with medium or low N-Gain scores. Media type also appears to play a role. Studies using three-dimensional visualisation and direct object manipulation, including IFP and augmented reality media, tend to report medium-to-high N-Gain more consistently than studies relying mainly on video or static digital slides. Differences linked to student grade level are less clear within the current sample, and this factor is noted here as an area requiring further investigation.

4.3 Pedagogical Implementation and Students' Psychological Response in the Literature

Beyond cognitive impact, a number of reviewed studies also reported on the implementation of learning activities and students' affective responses to interactive media. A study on remote collaboration using multitouch devices in elementary schools reported that the feature allowing digital objects to be shared between groups fostered more democratic communication patterns and motivated students' active engagement in group discussion. Another study on motivation-based interactive learning media reported a significant increase in students' affective engagement when the instructional design explicitly combined multimedia elements with a clear motivational structure.

To summarise how these thematic patterns were derived from the 34 reviewed articles, Figure 3 presents a thematic synthesis flowchart illustrating the coding process, from the four critical thinking indicators identified during coding to the cross-study patterns reported in this section.

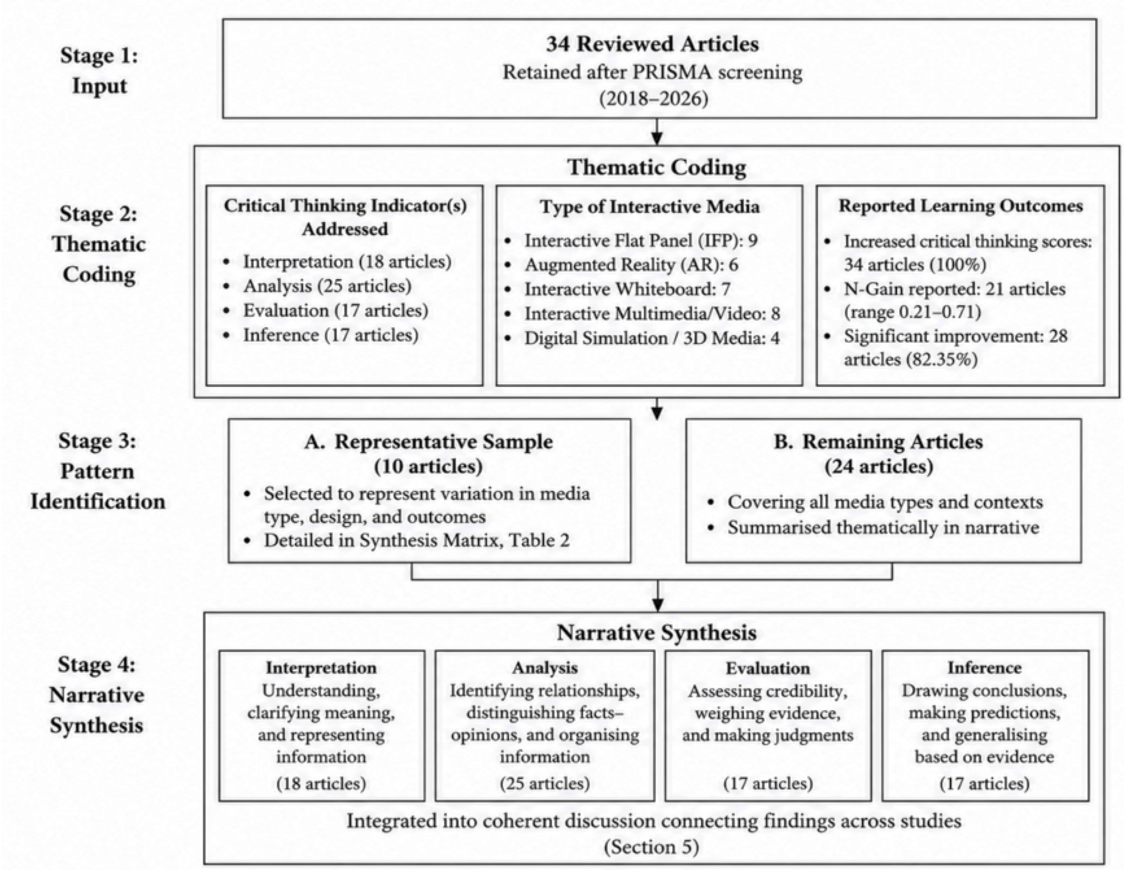

Figure 3. Flowchart of the thematic synthesis process across the 34 reviewed articles

As shown in Figure 3, the synthesis process moved from article-level coding toward an integrated discussion for each critical thinking indicator, which forms the basis of the analysis presented in Section 5.

Overall, the literature synthesis in this section confirms three key findings: first, interactive digital media assisted by IFP consistently contributes to the improvement of all four of Facione's critical thinking indicators; second, the effectiveness of this improvement is strongly influenced by the quality of pedagogical design rather than by device sophistication alone; and third, implementation quality and students' psychological responses also play an important role in determining the success of IFP integration. However, the literature that specifically examines IFP for Solar System instruction in Indonesian elementary schools remains very limited, reinforcing the urgency of developing the BUKITA media as a new contribution to this field.

4.4 Conceptual Model of BUKITA Media Implementation

The thematic patterns identified across the reviewed studies, particularly the stages of visual exploration, object manipulation, and collaborative discussion associated with improvements in critical thinking indicators, provide a basis for constructing a conceptual implementation model for the BUKITA media. The proposed model is illustrated in Figure 4.

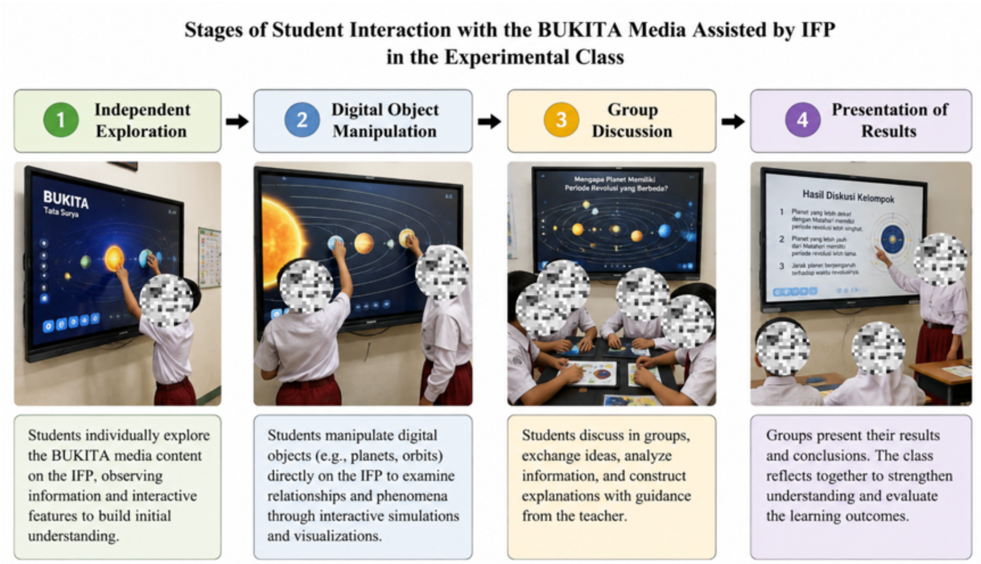

Figure 4. Conceptual *illustration of the proposed stages of student interaction with the BUKITA media assisted by IFP, from independent exploration to presentation of results*

This model outlines four sequential stages of student interaction with the BUKITA media assisted by IFP: independent exploration, digital object manipulation, group discussion, and presentation of results. Each stage corresponds to the reasoning process highlighted in the synthesis above, in which students first observe visual content individually, proceed to manipulate digital objects such as planets and orbits on the IFP, exchange ideas and analyse relationships in small groups, and finally present and reflect on their conclusions with guidance from the teacher.

5. DISCUSSION

The literature synthesis on the interpretation indicator shows that students who learn using interactive digital media are able to classify the characteristics of learning objects in a more organised manner than students taught through conventional methods. This improvement occurs through a staged visualisation process, in which students are first presented with a concrete visual representation on the touchscreen before being asked to group information according to relevant attributes, thereby systematically reducing the cognitive load involved in understanding abstract concepts. This process aligns with the dual-channel information-processing principle, which emphasises that the simultaneous integration of words and images facilitates the formation of meaningful mental representations (Mayer, 2024). This finding is also consistent with the results of augmented reality media development, which reported a medium-category improvement in the interpretation ability of elementary school students through three-dimensional visualisation (Sulthon et al., 2025). Nevertheless, several other studies show that the improvement in interpretation is not always significant when media are used without a clear accompanying activity strategy, as found in a systematic review of collaborative learning technology, which confirms that the strengthening of reasoning depends heavily on the alignment between strategy and inquiry stage (F. Chen & Chen, 2025). It can therefore be concluded that the improvement in the interpretation indicator through interactive media is conditional, making explicit pedagogical design a primary prerequisite for its success.

For the analysis indicator, the literature reveals that students who interact with dynamic simulations are able to examine logical relationships between variables more deeply than students who receive only verbal explanation from a teacher. This improvement chronologically begins with the opportunity for students to manipulate digital objects directly, for instance by changing viewing angles or simulation speed, which then encourages them to observe patterns of change and independently formulate cause-and-effect relationships. This exploratory process aligns with findings on Interactive Flat Panel media, which show that manipulative digital features significantly support students' transition from concrete understanding toward symbolic abstraction in geometry material (Hasanah et al., 2025). This alignment is further reinforced by research on the MABER media, which reported a significant improvement in the analytical ability of fourth-grade students through the manipulation of energy-related multimedia. Conversely, research on LCD media based on PjBL-STEM indicates that improvement in analysis is not always consistent when the description of digital content is not specified in detail, meaning that variation in results across studies must still be taken into account. The conclusion that can be drawn is that students' analytical ability develops optimally when media provide space for active manipulation rather than merely presenting passive visual content.

The evaluation indicator in the reviewed literature is generally measured through students' ability to test the validity of a statement based on data presented in digital media. The chronology of this ability's formation involves a process in which students are presented with several alternative interpretations of data and are then asked to compare supporting evidence before determining the most valid conclusion, a process that demands a higher level of cognitive engagement than simply recalling facts. This pattern is consistent with research on an inquiry-based learning model assisted by interactive media, which shows a significant improvement in the evaluation ability of elementary school students compared with conventional instruction (Simanjuntak et al., 2022). A psychometrically validated critical thinking evaluation instrument further confirms that evaluation is one of three core dimensions, together with analysis and inference, that carry the highest significance weight within the critical thinking construct (Rodríguez-Rojas et al., 2024). Nevertheless, not all studies report uniform results, as research on scientific literacy emphasises that evaluating the credibility of information requires contextual understanding that does not always develop through a single media intervention. It can therefore be concluded that strengthening the evaluation indicator requires sustained intervention rather than visualisation intensity alone.

For the inference indicator, the literature synthesis shows that students are able to formulate logical conclusions based on evidence presented visually, particularly when the media allow direct comparison between several objects or phenomena. The chronology of this ability's formation begins with the process of observing data patterns on the interactive screen, continues with the identification of regularities, and ultimately enables students to construct generalisations supported by concrete evidence. This finding is consistent with the results of an interactive STEAM-based storybook development, which reported a significant improvement in the synthesis and conclusion-drawing ability of third-grade students (Aryanti & Airlanda, 2024). A similar result was also found in research on a twenty-first-century skills curriculum model, which shows that the explicit integration of creative and reflective thinking skills contributes to strengthening students' inferential capacity (Dilekçi & Karatay, 2023). On the other hand, several studies show more moderate results, as reported in the development of three-dimensional Solar System media, which only achieved a medium N-Gain category, indicating that improvement in inference on astronomical topics requires a longer exposure duration than for other, more concrete topics (Pranata & Karyodiputro, 2026). The conclusion is that inferential ability develops gradually and is strongly influenced by the level of abstraction of the material being studied.

Beyond these four cognitive indicators, the literature also highlights the role of IFP-based instructional implementation in shifting classroom climate from teacher-centred to student-centred learning. The chronology of this shift begins with the capacity of the IFP device to facilitate direct visual collaboration in front of a large screen, which then encourages students to share ideas and collectively construct knowledge (Gan et al., 2015). A study on remote collaboration using multitouch devices in two elementary schools in England found that the gesture of sharing digital objects between groups built meaningful cognitive and social engagement in jointly solving problems (Beauchamp et al., 2026). This alignment of findings is further supported by a synthesis on technology-based collaborative inquiry, which confirms that collaborative activity strategies contribute significantly to improving students' argumentation skills (F. Chen & Chen, 2025). Nevertheless, research on the use of interactive whiteboards in long-term mathematics learning confirms that these collaborative benefits do not emerge automatically but depend heavily on how teachers design formative activities based on the device (I.-H. Chen et al., 2020). Effective IFP-based instructional implementation therefore requires deliberate pedagogical intervention by the teacher rather than device availability alone.

Students' motivation and psychological response represent another recurring theme in the reviewed literature. The chronology of motivational improvement generally begins with an immersive visual experience on a high-resolution screen, which then reduces students' extraneous cognitive load in understanding abstract concepts, thereby freeing cognitive capacity for meaningful processing. Research on the development of interactive learning media to enhance elementary school students' learning motivation reported a significant increase in enthusiasm and active engagement following the implementation of digital visualisation-based media (Hartono et al., 2025). This finding is consistent with research on the effectiveness of interactive media in increasing elementary school students' interest in learning, which emphasises the importance of engaging visual elements in sustaining student attention throughout the learning process (Ali et al., 2025). Nevertheless, research on motivation-based digital learning shows that stronger cognitive gains emerge specifically when interactivity is explicitly combined with a well-designed motivational structure, rather than by relying on visual appeal alone. The conclusion that can be drawn is that learning motivation serves as an important mediator, but not the sole determinant, of cognitive success in learning assisted by interactive media.

The literature on the validity of critical thinking measurement instruments also makes an important contribution to understanding how the findings above can be methodologically justified. The chronology of developing a valid instrument generally involves an expert judgement process using Aiken's V index before the instrument is field-tested on research subjects, thereby ensuring the empirical validity of measurements for the interpretation, analysis, evaluation, and inference indicators. This procedure is consistent with research on constructing content validity evidence for a mathematical problem-solving instrument, which confirms the importance of expert judgement as an initial step in developing higher-order thinking instruments (Setiawan et al., 2024). This is further reinforced by research on a critical thinking evaluation scale developed and validated across different populations, which shows that Facione's six cognitive dimensions can be measured consistently across cultural contexts (Rodríguez-Rojas et al., 2024). On the other hand, several reviewed studies did not report a detailed instrument validation process, resulting in methodological quality variation across studies that must be considered when interpreting the reported effect sizes. It can be concluded that the credibility of findings regarding the effectiveness of interactive media on critical thinking depends heavily on the quality of the measurement instrument used, not merely on the reported N-Gain magnitude.

The final part of this discussion highlights the overall implications of the literature synthesis for the need to develop the BUKITA media assisted by IFP. This chronology of argument is built from the finding that IFP has proven effective in the domains of mathematics and general science, yet its application specifically to Solar System material in Indonesian elementary schools remains very limited within the reviewed literature. This gap is consistent with findings regarding the scarcity of studies testing the effectiveness of structured content assisted by IFP in elementary schools, which confirm that the availability of hardware does not automatically guarantee the availability of appropriate pedagogical content. A comparison with research on three-dimensional Solar System media shows that astronomical topics require a more complex visualisation approach than other, more concrete science topics, meaning that adapting generic content is insufficient for achieving an optimal impact (Pranata & Karyodiputro, 2026). The four stages proposed in the conceptual model presented in Section 4.4 reflect this pedagogical requirement, positioning student manipulation and collaborative discussion as central rather than peripheral elements of the BUKITA design. Based on this overall synthesis, it can be concluded that the development of the BUKITA media assisted by IFP is a conceptually and empirically justified step to fill the identified research gap, while simultaneously making a new contribution to the primary education literature in the field of IPAS learning.

6. CONCLUSION

Based on the literature synthesis presented above, it can be concluded that interactive digital media assisted by an Interactive Flat Panel consistently contributes positively to the improvement of the four critical thinking indicators, namely interpretation, analysis, evaluation, and inference, at the elementary school level. The effectiveness of this improvement is strongly influenced by the appropriateness of pedagogical design, students' active engagement in manipulating digital objects, and the sustainability of instructional intervention, rather than being determined solely by the sophistication of the technological device employed. This review also reveals that the literature specifically addressing the use of IFP for Solar System material in Indonesian elementary schools remains very limited, indicating a genuine research gap between the availability of technological devices in schools and the availability of pedagogical content specifically designed for astronomical material.

This gap forms the basis of the recommendation that the development of the BUKITA media assisted by IFP should be prioritised as a concrete contribution to the field of primary education, particularly IPAS learning. Future research is recommended to conduct an empirical effectiveness test of the BUKITA media through a quasi-experimental design employing a psychometrically validated critical thinking instrument. Schools and education policymakers are also encouraged to promote the development of purposive digital content that maximises the interactive potential of IFP devices already available in various elementary education institutions.

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