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Development and Evaluation of BrunerFrame: An EIS-Based Ten-Frame for Improving First-Grade Students' Conceptual Understanding of Subtraction

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ABSTRACT

Objective: Many first-grade students struggle to develop conceptual understanding of subtraction because mathematics instruction predominantly emphasizes symbolic procedures while providing limited opportunities to connect concrete, visual, and symbolic representations. Although Ten-Frame media are widely used in early mathematics education, few instructional media systematically integrate Bruner's Enactive–Iconic–Symbolic (EIS) representations to facilitate meaningful conceptual learning. **Purpose:** This study aimed to develop and evaluate the effectiveness of BrunerFrame, an EIS-based Ten-Frame learning media, in enhancing first-grade students' conceptual understanding of subtraction. **Methods:** This study employed a Research and Development (R&D) approach using the ADDIE model, followed by a quasi-experimental pretest-posttest control group design involving 34 first-grade students from two elementary schools. Data were collected through expert validation, teacher and student response questionnaires, classroom observations, and conceptual understanding tests, then analyzed using descriptive and inferential statistics to examine the validity, practicality, and effectiveness of the developed media. **Results:** BrunerFrame demonstrated high validity, with material and media validation scores of 88.75% and 90.40%, respectively. Teacher and student practicality scores reached 87.00% and 86.00%, indicating that the media was highly practical for classroom implementation. Students who learned using BrunerFrame achieved significantly higher conceptual understanding than those receiving conventional instruction ($p < .001$), with a high normalized gain (N-Gain = 0.71) and a very large effect size (Cohen's $d = 2.64$), demonstrating substantial educational effectiveness. **Conclusion:** BrunerFrame is a valid, practical, and effective instructional medium that facilitates students' progression from concrete manipulation to visual representation and symbolic reasoning, thereby strengthening conceptual understanding of subtraction. **Research Implications:** These findings provide empirical evidence supporting the integration of Bruner's EIS theory into elementary mathematics media and offer a practical instructional model for promoting meaningful conceptual learning in primary classrooms. **Originality:** This study introduces BrunerFrame, a validated instructional medium that systematically integrates Bruner's Enactive, Iconic, and Symbolic representations within a Ten-Frame framework, extending the practical application of EIS theory to early subtraction learning.

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INTRODUCTION

Mathematical conceptual understanding is a fundamental objective of elementary mathematics education because it enables students to establish meaningful relationships among mathematical ideas rather than merely memorizing computational procedures. Students with strong conceptual understanding are better able to reason mathematically, solve unfamiliar problems, and apply their knowledge across different contexts. Consequently, early mathematical competence has consistently been recognized as a strong predictor of students' subsequent academic achievement

Herheim, (2023). Despite its importance, international evidence indicates that many students continue to experience difficulties in developing mathematical understanding. According to the OECD Programme for International Student Assessment (PISA) 2022, Indonesia achieved an average mathematics score of 366, substantially below the OECD average of 472, while only 18% of Indonesian students attained at least Level 2 proficiency compared with the OECD average of 69%. These findings indicate that many Indonesian students experience difficulties in mathematical reasoning and conceptual problem solving, emphasizing the urgent need to strengthen conceptual understanding from the earliest years of schooling. Similar concerns are reflected in Indonesia's National Assessment (Asesmen Nasional), which reports that elementary students' numeracy achievement remains below the expected competency level, particularly in solving contextual mathematical problems requiring conceptual understanding rather than procedural computation. Together, these international and national findings highlight the necessity of developing instructional innovations that promote meaningful conceptual learning in elementary mathematics (Björkhammer et al., 2024).

Meaningful mathematics learning requires students to construct knowledge through multiple representations that connect concrete experiences with increasingly abstract mathematical ideas. Erbilgin & Gningue (2023) argue that students' engagement with concrete objects, visual models, and symbolic representations significantly enhances mathematical communication, modeling, and conceptual understanding. Likewise, Zentgraf & Prediger (2024) found that explicitly connecting multiple mathematical representations enables students to establish meaningful relationships among visual, contextual, and symbolic forms, thereby strengthening conceptual understanding. This perspective is consistent with Bruner's theory, which proposes that mathematical learning progresses through three representational stages: Enactive, Iconic, and Symbolic (EIS). Supporting this theoretical framework, (Gilmore, 2023) emphasized that effective mathematics instruction should integrate conceptual knowledge, representational competence, and meaningful learning experiences rather than focusing exclusively on procedural performance. Therefore, mathematics learning in the first grade should provide opportunities for students to manipulate concrete materials, interpret visual representations, and gradually develop symbolic reasoning to facilitate meaningful conceptual understanding (Hui et al., 2023).

Although these theoretical principles are well established, classroom instruction frequently remains dominated by symbolic teaching practices. Classroom observations and diagnostic assessments conducted prior to this study at SD Negeri 2 Mojowetan revealed that subtraction instruction relied primarily on textbooks, worksheets, and teacher explanations, with limited opportunities for students to manipulate concrete learning media. Of the 22 first-grade students observed, 15 students (68.2%) were unable to connect concrete objects with subtraction symbols, 14 students (63.6%) relied mainly on memorized subtraction procedures when solving subtraction problems, and 13 students (59.1%) experienced difficulties interpreting pictorial representations of subtraction. Although many students were able to obtain correct answers through procedural calculation, they frequently failed to explain the mathematical relationships among concrete objects, visual representations, and symbolic notation. These findings indicate that students' procedural competence was not accompanied by adequate conceptual understanding, demonstrating the need for instructional media that systematically support students' progression from concrete experiences to abstract mathematical thinking (Dreher et al., 2024).

Bruner's theory proposes that children's conceptual understanding develops progressively through Enactive, Iconic, and Symbolic (EIS) modes of representation, in which learners move from direct manipulation of objects to visual representation and finally to abstract symbolic reasoning (Bruner, 1966). Recent studies have reaffirmed that this representational progression remains highly relevant for supporting conceptual understanding in mathematics, particularly when integrated with multiple representations and manipulative-based learningPrevious studies have consistently demonstrated that manipulative learning media improve elementary students' mathematical understanding by providing meaningful concrete learning experiences. Ten-Frame media have proven effective in enhancing number sense and early arithmetic skills, whereas Bruner's Enactive–Iconic–Symbolic (EIS) framework has been widely implemented as an instructional strategy to facilitate conceptual understanding (Lee, 2022; Wynne et al., 2026). Similarly, Kim (2025) reported that integrating multiple representations promotes meaningful mathematical reasoning and strengthens students' conceptual understanding. Dreher et al., (2024) further emphasized that high-quality mathematics instruction requires purposeful integration of multiple mathematical representations throughout the learning process. However, existing studies remain fragmented. Research on Ten-Frame has primarily focused on developing students' number sense and arithmetic skills without systematically integrating Bruner's EIS representations into a unified instructional medium. Conversely, studies grounded in Bruner's theory have generally implemented the EIS framework as a pedagogical strategy rather than translating it into a validated instructional media product. Furthermore, previous studies have rarely evaluated instructional media comprehensively in terms of validity, practicality, and effectiveness within a Research and Development (R&D) framework. Consequently, empirical evidence regarding an instructional medium that simultaneously integrates Ten-Frame, Bruner's EIS representations, and comprehensive product evaluation remains limited.

To address these gaps, this study developed BrunerFrame, an EIS-Based Ten-Frame instructional medium that integrates concrete manipulation, visual representation, and symbolic reasoning within a coherent learning sequence for first-grade subtraction learning. Unlike previous studies, BrunerFrame operationalizes Bruner's representational theory into a validated instructional medium while simultaneously evaluating its validity, practicality, and effectiveness through a Research and Development approach. Specifically, this study aims to (1) develop BrunerFrame using the ADDIE model, (2) examine its validity through expert evaluation, (3) evaluate its practicality based on teacher and student responses, and (4) determine its effectiveness in improving first-grade students' conceptual understanding of subtraction through quasi-experimental testing. The findings are expected to contribute theoretically by extending the application of Bruner's Enactive–Iconic–Symbolic theory into instructional media development and practically by providing teachers with an empirically validated learning medium that supports meaningful conceptual learning in early elementary mathematics (Sigus & Mädamürk, 2025).

METHOD

Research Design

A Research and Development (R&D) approach was adopted using the ADDIE instructional design model, which consists of Analysis, Design, Development, Implementation, and Evaluation (Shakeel et al., 2023). The ADDIE model was selected because it provides a systematic framework for designing, developing, validating, implementing, and evaluating instructional media. Integration of product development and effectiveness evaluation within a single research framework enabled BrunerFrame to be systematically designed, validated, implemented, and empirically tested before dissemination. Development and evaluation of BrunerFrame followed the ADDIE instructional design model in a systematic manner. As illustrated in Figure 1, the research procedure comprised seven interconnected stages, beginning with the analysis of learning needs and continuing through design, development, expert validation, revision, implementation, and evaluation to ensure the validity, practicality, and effectiveness of the developed instructional media.

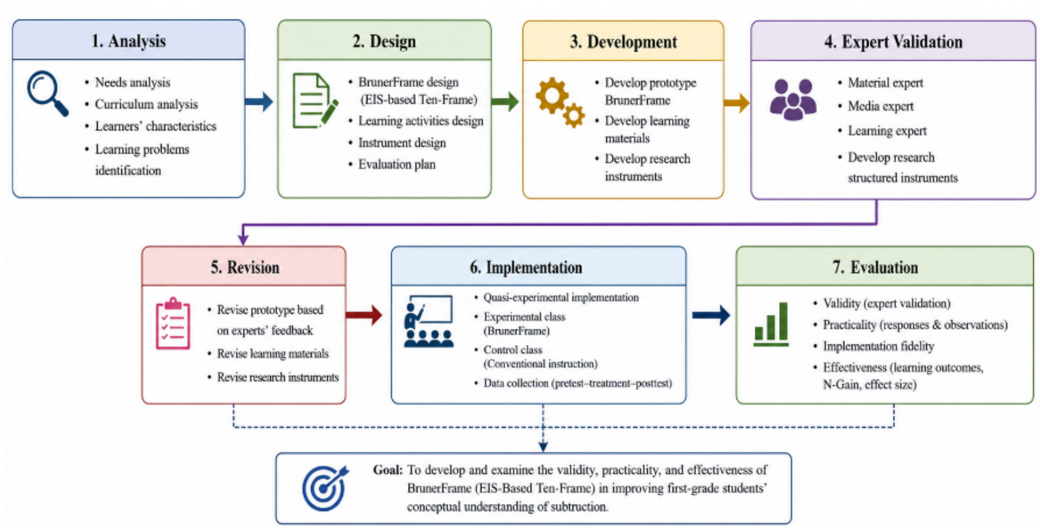

Figure 1. Research Procedure for Developing and Evaluating BrunerFrame Using the ADDIE Model

Variables of the Study

BrunerFrame, an EIS-Based Ten-Frame instructional medium, served as the independent variable in this study. Students' conceptual understanding of subtraction functioned as the dependent variable and was measured using a conceptual understanding test administered before and after the intervention. To strengthen the internal validity of the experiment, several control variables were maintained, including the learning topic, learning objectives, instructional duration, classroom teacher, and curriculum. The instructional media represented the only difference between the experimental and control groups, with BrunerFrame implemented in the experimental group and conventional instructional materials used in the control group.

Participants and Sampling

Participants were drawn from first-grade students enrolled in public elementary schools in Banjarejo District, Blora Regency, Indonesia. Two schools were purposively selected because they implemented the same national curriculum, had comparable student characteristics, similar classroom learning environments, and agreed to participate in the research. A total of 34 students participated in the study, comprising 16 students from SD Negeri 2 Sumberagung as the experimental group and 18 students from SD Negeri 3 Sumberagung as the control group. Purposive sampling was considered appropriate because the participating schools were intentionally selected according to predefined instructional and contextual criteria rather than through random selection. Prior to the intervention, both groups completed a pretest to determine their initial conceptual understanding of subtraction. Results of the pretest analysis indicated no statistically significant difference between the experimental and control groups, confirming equivalent baseline abilities before the intervention.

Development Procedure

BrunerFrame was developed following the five sequential phases of the ADDIE instructional design model: Analysis, Design, Development, Implementation, and Evaluation (Siller & Ahmad, 2024). The process began with an analysis of students' learning needs, curriculum requirements, and classroom challenges related to subtraction learning. Findings from this stage informed the design of BrunerFrame by integrating Bruner's Enactive–Iconic–Symbolic (EIS) learning theory into a Ten-Frame instructional medium that emphasized concrete, visual, and symbolic mathematical representations. Prototype construction was subsequently carried out during the development phase, followed by expert validation and product revision based on the validators' recommendations. Classroom implementation was then conducted in the experimental group to examine the applicability of the developed media under authentic learning conditions. The final evaluation phase assessed the quality of BrunerFrame in terms of its validity, practicality, implementation fidelity, and instructional effectiveness.

Instrument Validation and Reliability

Prior to classroom implementation, BrunerFrame and all research instruments underwent expert validation involving three validators, consisting of two lecturers from Universitas PGRI Semarang with expertise in mathematics education and instructional media and one elementary school principal with expertise in elementary mathematics instruction. Each validator independently evaluated the prototype using structured validation instruments. After the individual evaluations, a consensus discussion was conducted to review the evaluation results and formulate recommendations for improvement before the media was revised.

The validators assessed content accuracy, instructional design, media quality, language clarity, usability, learning activities, and consistency with Bruner's Enactive–Iconic–Symbolic (EIS) learning principles. Following revisions, the material validation score reached 88.75%, whereas the media validation score reached 90.40%, both categorized as highly valid based on the predetermined interpretation criteria, indicating that BrunerFrame was appropriate for classroom implementation. The internal consistency of the research instruments was examined using Cronbach's Alpha, producing a coefficient of 0.89, indicating good reliability because the value exceeded the minimum acceptable threshold of 0.70 for educational research.

Research Instruments

Data were collected using expert validation sheets, teacher response questionnaires, student response questionnaires, classroom observation sheets, and a conceptual understanding test. The expert validation sheets were designed to evaluate the content accuracy, instructional design, media quality, language clarity, and alignment of BrunerFrame with Bruner's Enactive–Iconic–Symbolic (EIS) learning principles. Teacher and student response questionnaires assessed the practicality of the developed instructional media, whereas classroom observation sheets examined the fidelity of instructional implementation. The conceptual understanding test measured students' ability to connect concrete, visual, and symbolic representations of subtraction, reflecting meaningful mathematical understanding based on Bruner's representational theory (Herheim, 2023; Hankeln & Prediger, 2025). Prior to implementation, all instruments underwent expert validation and revision, and their internal consistency was confirmed using Cronbach's Alpha ($\alpha = 0.89$), indicating good reliability because the coefficient exceeded the minimum acceptable threshold of 0.70 for educational research. Table 1 summarizes the research instruments, including their data sources, measured aspects, main indicators, and corresponding data analysis techniques used throughout the study.

Table 1. Research Instruments

Instrument	Data Source	Measured Aspect	Main Indicators	Data Analysis
Material expert validation sheet	Material expert	Validity of subtraction content in BrunerFrame	Suitability with learning outcomes, accuracy of mathematical concepts, suitability with first-grade students' characteristics, implementation of Enactive, Iconic, and Symbolic stages, systematic material sequence, and feasibility of the material	Percentage formula and validity criteria
Media expert validation sheet	Media expert	Validity of BrunerFrame media design	Media display, media quality, safety, usefulness, suitability with Bruner's EIS stages, and transition from concrete to abstract learning	Percentage formula and validity criteria
Learning expert validation sheet	Learning expert	Validity of the instructional procedure	Alignment with learning objectives, EIS-based learning sequence, student-centered strategy, classroom implementation, and potential learning impact	Percentage formula and validity criteria
Teacher response questionnaire	First-grade teacher	Practicality of BrunerFrame from the teacher's perspective	Ease of use, suitability with subtraction learning, media benefits, media quality, and feasibility for classroom use	Percentage formula and practicality criteria
Student response questionnaire	First-grade students	Practicality of BrunerFrame from students' perspective	Interest, ease of use, perceived benefit, learning activeness, confidence, motivation, and willingness to use the media again	Percentage formula and practicality criteria
Learning implementation observation sheet	Observer	Implementation of EIS-based learning activities	Preliminary activities, Enactive stage, Iconic stage, Symbolic stage, and closing activities	Percentage formula and implementation criteria
Conceptual understanding test	Experimental and control class students	Students' conceptual understanding of subtraction	Understanding subtraction through concrete objects, visual representation, subtraction symbols, and subtraction problem solving	Shapiro-Wilk test, Levene's test, independent-samples t-test, N-Gain, and Cohen's d effect size

As presented in Table 1, the combination of validation instruments, practicality questionnaires, classroom observations, and conceptual understanding tests enabled a comprehensive evaluation of BrunerFrame in terms of its validity, practicality, implementation fidelity, and instructional effectiveness.

Experimental Procedure

Implementation of the intervention consisted of four instructional meetings, each lasting 2 × 35 minutes, excluding the pretest and posttest sessions. Learning activities in the experimental group followed Bruner's Enactive–Iconic–Symbolic (EIS) instructional sequence. Meeting 1 emphasized the Enactive stage, during which students manipulated counters using BrunerFrame to construct subtraction concepts through direct experiences. Meeting 2 focused on the Iconic stage by engaging students in interpreting pictorial representations of subtraction through Ten-Frame illustrations. Meeting 3 addressed the Symbolic stage, where concrete and visual representations were translated into mathematical symbols and subtraction equations. Meeting 4 integrated all three representational stages, enabling students to solve subtraction problems by flexibly connecting concrete manipulation, visual representation, and symbolic reasoning. Guided reflection at the end of each lesson encouraged students to relate concrete experiences, pictorial representations, and symbolic notation, thereby reinforcing conceptual understanding through multiple mathematical representations (Erbilgin & Gningue, 2023; Zentgraf & Prediger, 2024; Kim, 2025). Conventional textbook-based instruction was implemented in the control group using the same subtraction content, learning objectives, instructional duration, and classroom teacher, with the instructional media representing the only difference between the two groups.

Ethical Considerations

Permission to conduct the study was obtained from the participating schools before data collection. Teachers, parents, and students were informed about the objectives and procedures of the study, and participation was voluntary. Students' identities were anonymized during data analysis and reporting to ensure confidentiality. All research procedures complied with institutional ethical standards for educational research.

Data Analysis

Descriptive statistics were used to evaluate the validity, practicality, and implementation fidelity of BrunerFrame by calculating percentage scores according to predetermined interpretation criteria. Inferential statistics were employed to examine the effectiveness of the developed instructional media. Before hypothesis testing, the assumptions of normality and homogeneity were examined using the Shapiro–Wilk test and Levene's test, respectively. Because the pretest analysis indicated no statistically significant difference between the experimental and control groups, the independent-samples *t*-test, supported by normalized gain (N-Gain) analysis, was considered appropriate for comparing students' posttest performance without requiring covariance adjustment. N-Gain analysis was employed to determine the magnitude of students' learning improvement following the intervention, whereas Cohen's *d* effect size was calculated to determine the practical significance of the treatment beyond statistical significance (Hedges et al., 2023). All statistical analyses were conducted at a significance level of $\alpha = .05$.

RESULTS

Results are presented according to the R&D objectives and the effectiveness testing procedure. Data analysis focused on product validity, practicality, learning implementation, and students' conceptual understanding of subtraction after using BrunerFrame: EIS-Based Ten-Frame Learning Media.

Product Validation Results

Product feasibility was evaluated through expert review prior to classroom implementation. The evaluation examined content quality, instructional design, media functionality, and alignment with Bruner's Enactive–Iconic–Symbolic (EIS) learning principles.

Table 2. Results of Material Expert Evaluation

Evaluation Aspect	Score	(%)	Interpretation
Content quality	71	88.75	Highly valid

Content evaluation produced a score of 88.75%, indicating that the instructional material satisfied the predetermined criteria for high validity and was appropriate for first-grade subtraction learning.

Table 3. Results of Media Expert Evaluation

Evaluation Aspect	Score	(%)	Interpretation
Display quality	23	92.00	Highly valid
Media quality	22	88.00	Highly valid
Alignment with Bruner's EIS theory	23	92.00	Highly valid
Usefulness	23	92.00	Highly valid
Overall feasibility	22	88.00	Highly valid
Overall	113	90.40	Highly valid

Media evaluation yielded an overall validity score of 90.40%, demonstrating that the developed media fulfilled the predetermined criteria for classroom use. Minor revisions recommended by the validators were incorporated before implementation, primarily involving colour refinement, clearer usage instructions, and improved material durability.

Practicality Results

Practicality of BrunerFrame was examined through teacher and student response questionnaires administered after classroom implementation. The evaluation focused on usability, instructional suitability, perceived benefits, and overall classroom applicability.

Table 4. Teacher Responses to the Practicality of BrunerFrame

Evaluation Aspect	Score	(%)	Interpretation
Ease of use	18	90.00	Highly practical
Suitability with learning	17	85.00	Highly practical
Media benefits	18	90.00	Highly practical
Media quality	17	85.00	Highly practical
Overall evaluation	17	85.00	Highly practical
Overall	87	87.00	Highly practical

Teacher responses yielded an overall practicality score of 87.00%, indicating that BrunerFrame satisfied the criteria for high practicality. Strong ratings across all evaluation aspects suggest that the instructional media can be implemented effectively to support subtraction instruction with minimal instructional adjustment. Student perceptions were subsequently analysed to examine the practicality of BrunerFrame from the learners' perspective.

Table 5. Student Responses to the Practicality of BrunerFrame

Evaluation Aspect	Score	(%)	Interpretation
Interest	280	87.50	Highly practical
Ease of use	260	86.67	Highly practical
Media benefits	250	83.33	Highly practical
Learning motivation	242	86.43	Highly practical
Overall	1,032	86.00	Highly practical

Student responses produced an overall practicality score of 86.00%, demonstrating that BrunerFrame was well accepted during classroom learning. Positive ratings across all aspects indicate that the instructional media promoted engagement, ease of use, learning motivation, and conceptual understanding of subtraction. Taken together, the teacher and student responses confirm that BrunerFrame satisfied the predetermined practicality criteria and was suitable for implementation in authentic first-grade mathematics classrooms.

Learning Implementation Result

Implementation fidelity was examined through classroom observations to determine whether the learning activities followed Bruner's Enactive–Iconic–Symbolic (EIS) instructional sequence during classroom implementation.

Table 6. Classroom Implementation of BrunerFrame

Evaluation Aspect	Score	(%)	Interpretation
EIS-based learning implementation	79	92.94	Highly implemented

Classroom observation yielded an implementation score of 92.94%, indicating that the instructional procedures were implemented with high fidelity. Learning activities across the Enactive, Iconic, and Symbolic stages were conducted according to the planned instructional sequence, enabling students to manipulate concrete materials, interpret visual representations, and construct subtraction concepts using mathematical symbols. High implementation fidelity indicates that the effectiveness of BrunerFrame was evaluated under instructional conditions consistent with the intended design.

Effectiveness of BrunerFrame

Having established the validity, practicality, and successful classroom implementation of BrunerFrame, the next analysis examined its effectiveness in improving first-grade students' conceptual understanding of subtraction. Effectiveness was evaluated through descriptive statistics, assumption testing, hypothesis testing, normalized gain (N-Gain), and effect size analysis.

Descriptive Statistics

Descriptive statistics were calculated to compare students' conceptual understanding before and after the intervention.

Table 7. Descriptive Statistics of Students' Conceptual Understanding Scores

Group	Test	N	Mean	SD	Min	Max
Experimental	Pretest	16	51.25	7.19	40	65
Experimental	Posttest	16	86.19	5.21	78	95
Control	Pretest	18	52.06	5.22	44	62
Control	Posttest	18	73.89	4.10	67	81

Comparable pretest performance was observed between the experimental and control groups, indicating equivalent baseline conceptual understanding before the intervention. Marked improvement occurred in both groups after instruction; however, the experimental group achieved a substantially higher posttest mean than the control group. These descriptive findings suggest that BrunerFrame contributed more effectively to improving students' conceptual understanding of subtraction.

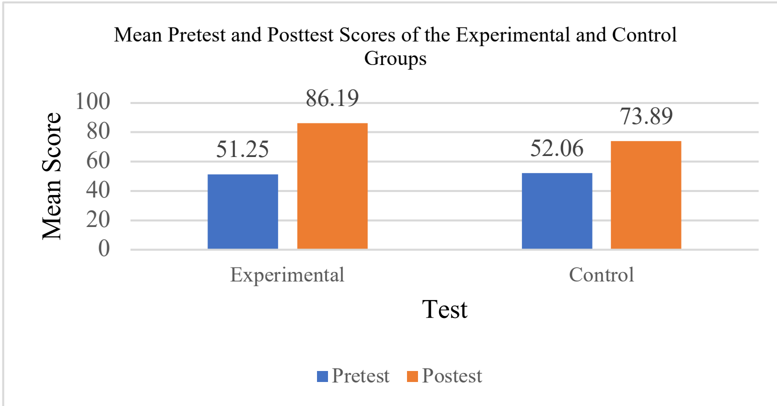

Figure 2. Mean Pretest and Posttest Scores of the Experimental and Control Groups

Figure 2 visually illustrates the differences in students' conceptual understanding before and after the intervention. Similar pretest means were observed across both groups, whereas the experimental group demonstrated considerably greater improvement following instruction with BrunerFrame.

Assumption Testing
Assumption testing was performed before inferential analysis to verify the suitability of parametric statistical procedures.

Table 8. Normality Test Results

Variable	Group	Shapiro–Wilk	*p*	Interpretation
Pretest	Experimental	.954	.552	Normal
Pretest	Control	.976	.893	Normal
Posttest	Experimental	.967	.796	Normal
Posttest	Control	.978	.922	Normal

All Shapiro–Wilk significance values exceeded .05, indicating that the data were normally distributed.

Table 9. Homogeneity Test Result

Test	F	*p*	Interpretation
Levene's Test	1.335	.256	Homogeneous

Levene's test yielded a significance value greater than .05, confirming homogeneous variances between the two groups. Consequently, the assumptions required for the independent-samples *t*-test were satisfied.

Hypothesis Testing
Hypothesis testing was conducted using an independent-samples *t*-test to compare posttest performance between the two groups.

Table 10. Independent-Samples *t*-Test Result

Comparison	*T*	df	*P*	Mean Difference
Posttest	7.696	32	< .001	12.299

Independent-samples *t*-test analysis revealed a statistically significant difference between the experimental and control groups ($t(32) = 7.696$, $p < .001$). Students who learned using BrunerFrame achieved significantly higher conceptual understanding scores than those receiving conventional instruction.

N-Gain Analysis
Normalized gain analysis was performed to determine the magnitude of students' learning improvement following the intervention.

Table 11. N-Gain Analysis

Group	Mean N-Gain	Category
Experimental	0.71	High
Control	0.46	Moderate

Learning gains in the experimental group reached the high category, whereas the control group demonstrated lower improvement. These findings indicate that BrunerFrame was more effective than conventional instruction in promoting conceptual understanding of subtraction.

Effect Size Analysis
Effect size analysis was conducted to determine the practical significance of the intervention beyond statistical significance.

Table 12. Effect Size Analysis

Effect Size	Value	Interpretation
Cohen's *d*	2.644	Very large
Hedges' *g*	2.582	Very large
Glass's Δ	3.000	Very large

Effect size analysis demonstrated a very large educational impact, as indicated by Cohen's $d = 2.644$. Such a substantial effect suggests that BrunerFrame produced not only statistically significant improvement but also meaningful educational benefits. The magnitude of the effect is likely attributable to the integration of concrete manipulation, multiple mathematical representations, systematic transitions across Bruner's Enactive–Iconic–Symbolic (EIS) stages, active student engagement, and conceptual scaffolding, all of which supported meaningful conceptual understanding of subtraction (Erbilgin & Gningue, 2023; Zentgraf & Prediger, 2024).

Summary of Findings
Overall, the findings indicate that BrunerFrame fulfilled all predetermined criteria for instructional quality and effectiveness. High validity, practicality, and implementation fidelity confirmed the quality and classroom feasibility of the developed instructional media. Inferential analyses consistently demonstrated superior learning outcomes in the experimental group compared with the control group, supported by high normalized learning gains and a very large effect size, indicating substantial educational benefits. Collectively, these findings confirm that BrunerFrame provides a valid, practical, and effective instructional medium for strengthening first-grade students' conceptual understanding of subtraction.

DISCUSSION

BrunerFrame effectively enhanced first-grade students' conceptual understanding of subtraction by facilitating a systematic progression from concrete manipulation to visual representation and symbolic reasoning, as evidenced by the significantly higher posttest performance, high normalized gain, and very large effect size achieved by the experimental group. Meaningful conceptual learning occurred because students actively connected objects, images, and mathematical symbols rather than relying solely on procedural computation, supporting Bruner's Enactive–Iconic–Symbolic (EIS) theory and the view that conceptual understanding develops through coordinated multiple representations (Drijvers & Sinclair, 2024). Consistent evidence has also been reported by Abraham and Prediger (2025); (Jäder & Johansson, 2025) who found that representational learning strengthens students' ability to recognize underlying mathematical structures and promotes deeper conceptual reasoning. Unlike previous studies, which primarily employed Ten-Frame as a manipulative or implemented Bruner's EIS as a teaching strategy, the present study systematically integrated both into a validated instructional medium developed through a Research and Development framework. Such integration represents the principal contribution of this study by extending Bruner's representational theory into an empirically validated instructional product that proved to be valid, practical, and effective for improving first-grade students' conceptual understanding of subtraction in authentic classroom settings (Fujita et al., 2025).

Previous research has consistently demonstrated that manipulatives and multiple representations improve students' mathematical understanding by facilitating meaningful connections between concrete experiences and abstract concepts. Studies by (Anam et al., 2024; Post & Prediger, 2024; Hsu & Hsu, 2025) reported that instructional approaches integrating multiple representations enhance students' conceptual reasoning by helping them recognize mathematical relationships across different forms. Likewise, (Quane & Ní Ríordáin, 2025) emphasized the pedagogical value of manipulatives in supporting young learners' mathematical thinking, while (Quane & Ní Ríordáin, 2025) highlighted the growing importance of instructional tools that actively engage students in constructing mathematical ideas rather than passively receiving information. Despite these advances, previous studies have generally examined Ten-Frame manipulatives, multiple representations, or Bruner's Enactive–Iconic–Symbolic (EIS) theory as separate instructional approaches, with limited attention to integrating these elements into a systematically developed and empirically validated instructional product. Findings of the present study extend this body of knowledge by demonstrating that BrunerFrame combines concrete manipulation, visual representation, and symbolic reasoning within a single EIS-based Ten-Frame medium developed through the ADDIE model and comprehensively evaluated in terms of validity, practicality, and effectiveness (Anwar et al., 2025). Such integration represents the principal contribution of this study by providing empirical evidence that representational progression can be translated into an instructional product capable of strengthening first-grade students' conceptual understanding of subtraction in authentic classroom settings. Several factors contributed to the effectiveness of BrunerFrame in improving students' conceptual understanding of subtraction. Concrete manipulation enabled students to construct mathematical meaning before introducing abstract symbols, while the Enactive–Iconic–Symbolic (EIS) sequence supported smooth transitions across multiple representations. Conceptual scaffolding and active student engagement further encouraged learners to connect concrete objects, visual models, and symbolic notation through meaningful learning activities. Consistent with previous studies, coordinated multiple representations promote deeper conceptual reasoning and strengthen mathematical understanding (Gilmore, 2023; Jäder & Johansson, 2025). These instructional characteristics suggest that the effectiveness of BrunerFrame resulted from the integration of representational learning, structured instructional design, and active classroom participation rather than from the use of manipulatives alone.

Findings of this study extend Bruner's Enactive–Iconic–Symbolic (EIS) theory by demonstrating that representational progression can be operationalized into a systematically developed and empirically validated instructional medium rather than remaining solely as a pedagogical framework. BrunerFrame also reinforces the theory of representational learning by providing evidence that integrating concrete, visual, and symbolic representations within a coherent instructional sequence promotes deeper conceptual understanding of subtraction. These findings contribute to mathematics education by bridging learning theory and instructional media design for early primary mathematics.

Application of BrunerFrame demonstrates that meaningful subtraction learning can be achieved through a structured progression of concrete, visual, and symbolic representations. Primary school teachers may adopt this instructional sequence to strengthen students' conceptual understanding, while curriculum developers can integrate EIS-based learning principles into mathematics curricula. Schools are encouraged to facilitate the use of manipulative-based learning media, and future instructional media development may apply the BrunerFrame framework to broader elementary mathematics topics.

Several limitations should be considered when interpreting the findings. The study involved a relatively small sample drawn from only two elementary schools, which may limit the generalizability of the results. Evaluation was restricted to the topic of subtraction in first-grade mathematics; therefore, the effectiveness of BrunerFrame for other mathematical concepts remains uncertain. In addition, differences in teacher implementation and students' initial enthusiasm toward a newly introduced instructional medium (novelty effect) may have influenced the observed learning outcomes despite efforts to maintain consistent instructional conditions.

Future research should examine the effectiveness of BrunerFrame using larger and more diverse samples across different educational settings to improve the generalizability of the findings. Further studies are also encouraged to extend its application to other elementary mathematics topics, develop digital or technology-enhanced versions of BrunerFrame, and conduct longitudinal investigations to evaluate the sustainability of its effects on students' conceptual understanding over time.

CONCLUSION

Development of BrunerFrame demonstrates that integrating Bruner's Enactive–Iconic–Symbolic (EIS) theory into a systematically designed Ten-Frame instructional medium provides an effective approach for strengthening first-grade students' conceptual understanding of subtraction. Rather than functioning solely as a manipulative, BrunerFrame offers a structured representational pathway that connects concrete manipulation, visual representation, and symbolic reasoning, thereby supporting meaningful mathematical learning beyond procedural computation.

Theoretical contribution of this study lies in extending Bruner's EIS theory into a validated instructional product, providing empirical evidence that representational progression can be operationalized through instructional media developed using the ADDIE model. Practical contribution lies in offering teachers, curriculum developers, and instructional media designers an evidence-based model for reducing symbol-dominant mathematics instruction through systematic integration of concrete, visual, and symbolic representations.

Several limitations should be acknowledged. The study involved a relatively small sample from two elementary schools and focused exclusively on subtraction learning in first grade. In addition, possible teacher and novelty effects may have influenced students' responses during the intervention despite efforts to maintain consistent instructional conditions. Future research should examine the effectiveness of BrunerFrame with larger and more diverse samples, across different mathematical topics and educational contexts, while also exploring digital or hybrid adaptations and longitudinal implementation to evaluate the sustainability of students' conceptual understanding over time.

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AUTHOR CONTRIBUTION STATEMENT

SU: Conceptualization, methodology, investigation, data collection, formal analysis, and writing original draft. **BAS:** Validation, supervision, methodology review, and writing review and editing. **AB:** Supervision, validation, data interpretation, and final manuscript review. All authors have read and approved the final manuscript.

AI DISCLOSURE STATEMENT

The author used ChatGPT during the preparation of this work to assist with language refinement, structural organization, and academic writing clarity. After using the tool, the author thoroughly reviewed, revised, and edited the content as needed and takes full responsibility for the content of the publication.

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