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The Capacity of NGSS-Based Teaching Materials Integrated Game Discovery (BANDI) to Improve Scientific Argumentation Skills of High School Students

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Abstract: Scientific argumentation is a crucial competency for students to meet the challenges of 21st-century learning. This study investigates the potential of NGSS-based teaching materials integrated with Game Discovery (BANDI) to enhance high school students' scientific argumentation skills. The objective is to examine the practicality and effectiveness of BANDI in supporting argumentation-oriented learning. A quasi-experimental design with a nonequivalent pretest–posttest control group was employed, involving class X MIPA students selected through cluster random sampling. Data were collected using tests, observation sheets, and questionnaires, then analyzed through descriptive statistics, N-Gain, and inferential tests (Independent T-Test and Mann-Whitney). Results indicate that BANDI achieved a high level of practicality, with implementation scores ranging from 73.44% to 96.88% and positive responses from students (81.86%) and teachers (88.39%). Effectiveness was confirmed by N-Gain scores in the moderate category (0.3–0.7) and statistically significant differences in posttest results, where the experimental group outperformed the control group (52.75 vs. 17.75, $p < 0.001$). These findings conclude that BANDI is both practical and effective in improving scientific argumentation skills. Scientifically, this study highlights the importance of integrating NGSS dimensions, discovery learning, and game elements to foster student engagement and reasoning. It is recommended that educators adopt BANDI to strengthen 21st-century competencies, particularly scientific argumentation in science education.

Keywords: BANDI, Capacity, Scientific argumentation skills.

Introduction

Scientific argumentation is a crucial practice in science education, enabling learners to understand phenomena and critically evaluate claims through evidence-based reasoning, while fostering conceptual change and critical thinking (Li *et al.*, 2022). At the same time, game-based and gamified learning approaches are increasingly applied in STEM education for their ability to enhance motivation, engagement, and learning outcomes (Ortiz-Rojas *et al.*, 2025; Montenegro-Rueda *et al.*, 2023; Chen *et al.*, 2023). Gamification elements such as leaderboards, rewards, and collaboration further promote creativity, active participation, and scientific argumentation skills (Lee & Lai, 2024; Moral-Sánchez *et al.*, 2022). Integrating both approaches has shown synergistic effects in strengthening scientific understanding, learning motivation, and the construction of high-quality arguments (Lin & Hung, 2025).

Game-based learning environments that include feedback, challenge, and collaboration are particularly effective in fostering argumentation skills and engagement. These environments support modeling, reflection, and iterative feedback, which are crucial for developing students' ability to construct and critique arguments (Noroozi *et al.*, 2020; Talib *et al.*, 2019). Meta-analyses indicate that digital game-based STEM education produces moderate to large improvements in learning achievement compared to traditional methods, with added game-design elements further enhancing learning outcomes (Wang *et al.*, 2022; Gui *et al.*, 2023). Game-based approaches also promote reasoning, problem-solving, and creativity, especially when integrated into technology and engineering courses (Talib *et al.*, 2019).

Despite these benefits, the implementation of game-based learning in relation to scientific argumentation remains limited in many educational contexts. Recent studies show that classrooms often lack systematic integration of game-based learning to effectively support the development of argumentation skills (Videnovik *et al.*, 2023). Research further indicates that students still struggle to construct counterarguments, justify claims with evidence, and critically evaluate opposing viewpoints, especially in conventional learning environments where innovative pedagogical approaches are rarely implemented (Noroozi *et al.*, 2020). This limitation is partly due to teachers' insufficient expertise in designing and facilitating educational games, as well as difficulties in aligning game mechanics with curricular objectives and assessment standards (Videnovik *et al.*, 2023).

Therefore, this study introduces a novel NGSS-based teaching material integrated with a game-discovery approach (BANDI) to address these challenges. The urgency lies in equipping students with robust argumentation skills that are essential for scientific literacy and 21st-century competencies. The objectives are to examine BANDI's practicality in the classroom and its effectiveness in improving students' scientific argumentation skills.

Materials and Methods

Time and Location

The research was conducted from March to May 2023 at SMAN 01 Labuhan Haji, East Lombok, West Nusa Tenggara, Indonesia. The location was chosen based on accessibility and the availability of high school students as the target population for NGSS-based teaching materials integrated with Game Discovery (BANDI).

Research Design/Type

This study employed a quasi-experimental design with a nonequivalent pretest–posttest control group. This design allows for the comparison of learning outcomes between students taught using BANDI and those taught using conventional methods, even though the sample groups were pre-determined by the school (Audrey *et al.*, 2019).

Population and Research Sample

The population consisted of all students of class X MIPA at SMAN 01 Labuhan Haji during the 2022/2023 academic year. A total of two classes were selected as research samples through cluster random sampling, with one class assigned as the experimental group and the other as the control group. Cluster random sampling was chosen because the research design did not allow re-grouping of existing classes (Creswell & Creswell, 2018). The experimental group received treatment using BANDI, while the control group was taught using conventional media. The research variables consisted of independent variables (learning using BANDI and conventional media) and dependent variables (students' scientific argumentation skills). Data collection was carried out through observation sheets, scientific argumentation skill tests, and teacher–student response questionnaires. The tools used included BANDI teaching materials, worksheets, and statistical test instruments.

Research Procedure

The research procedure consisted of four main stages. First, preparation involved developing BANDI teaching materials integrated with NGSS and game discovery elements, and validating the instruments through expert review. Second, the implementation stage began with administering pretests to both control and experimental groups, followed by the learning treatment: the experimental group was taught using BANDI, while the control group received instruction with conventional media. Third, posttests were administered to both groups to assess improvement in scientific argumentation skills. Fourth, supporting data were collected, including teacher and student responses as well as observer assessments of learning implementation.

Data Analysis

The data analysis consisted of practicality and effectiveness testing. Practicality was analyzed by calculating the percentage of teacher and student responses and observer assessments, which were then converted into practicality categories (Arikunto, 2010). Effectiveness was analyzed using the N-Gain formula to measure improvement in students' scientific argumentation skills:

$$\text{N-gain (g)} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maksimum Score} - \text{Pretest Score}}$$

(Sundayana, 2014)

The N-Gain values were interpreted using the following criteria: low (0.0 < g < 0.30), moderate (0.30 ≤ g < 0.70), and high (0.70 ≤ g ≤ 1.00) (Sundayana, 2014). Furthermore, inferential statistical tests were applied to examine the significance of differences between groups. Data that met normality and homogeneity assumptions were analyzed using the Independent T-test, while non-parametric data were analyzed using the Mann–Whitney test. All statistical analyses were performed at a significance level of 0.05.

Result and Discussion

Practicality of BANDI in Classroom Learning

The practicality test aimed to determine the ease of use and feasibility of BANDI in classroom learning. Data from teachers and students showed an average response of 81.86% and 88.39%, respectively, which falls into the very practical category (Table 1). Observers also recorded that lesson implementation using BANDI was well executed, with scores ranging between 73.44% and 96.88%. These findings indicate that BANDI is both attractive and user-friendly, making it feasible for regular classroom application.

Table 1. Teacher and student response to the practicality of BANDI

Items	Student Response	Teacher Response
Attractiveness of BANDI design	76.00%	75.00%
Cover describes the content of BANDI	82.00%	100.00%
The joy of using BANDI	89.00%	75.00%
Increased learning motivation using BANDI	81.00%	87.50%
Comprehensiveness of material presentation in BANDI	79.00%	87.50%
Increased depth of understanding of the material	87.00%	87.50%
Increased learning activeness	79.00%	87.50%
Ease of text reading	86.00%	100.00%
Attractiveness of the appearance of teaching materials	81.00%	75.00%
Increased ease of understanding the material	91.00%	87.50%
Ease of understanding the image display	80.00%	100.00%
Improved understanding of the material with the help of pictures and illustrations	77.00%	100.00%
Ease of sentences used	79.00%	87.50%
Communicative use of language	79.00%	87.50%
Average	81.86%	88.39 %
SD	0.046	0.091

The practicality of BANDI was evaluated through student and teacher responses as well as observer assessments of classroom implementation. Results showed that BANDI was categorized as very practical, with response scores of 81.86% from students and 88.39% from teachers, while observers rated lesson implementation between 73.44% and 96.88%. These findings confirm that BANDI is user-friendly and suitable for science classrooms, as it provides clear material organization, interactive design, and motivational features. The high practicality also indicates that teachers and students did not encounter significant difficulties in applying BANDI, suggesting its potential for broad classroom use.

When compared to previous research, these findings are consistent with studies showing that ICT-based interactive games and discovery learning modules can significantly enhance student motivation, engagement, and learning outcomes (Utaminingsih *et al*., 2022; Majdi & Faizatina, 2025; Zhao *et al*., 2022; Husna *et al*., 2025; Ratminingsih *et al*., 2018). For example, the use of platforms like Bamboozle has been found to foster communication, collaboration, and a healthy competitive spirit among students, while also making abstract concepts more accessible and increasing motivation (Majdi & Faizatina, 2025). Similarly, game-based interactive digital modules have been shown to boost active participation and facilitate understanding of learning materials (Husna *et al*., 2025).

The practicality of the BANDI module is particularly notable, as it not only integrates multiple NGSS dimensions with discovery learning syntax but also offers an engaging design and deeper conceptual learning, surpassing the practicality reported in earlier studies. This underscores the importance of practicality as a key factor for the sustainability of instructional innovations. However, a limitation remains in that practicality assessments often rely on perception-based data; thus, further classroom trials across diverse educational contexts are needed to provide stronger evidence of usability and effectiveness (Zhao *et al*., 2022; Hanatan *et al*., 2023; Hendra *et al*., 2022; Utami *et al*., 2020).

Effectiveness of BANDI in Improving Scientific Argumentation Skills

The effectiveness of BANDI in enhancing students' scientific argumentation skills can be seen in Tables 9, 10, and 11, which present the results of pre-test and post-test scores, the N-Gain analysis, and the detailed improvement across each argumentation indicator. Table 9 shows a significant increase in students' argumentation scores after the implementation of BANDI. Table 10 further illustrates the effectiveness through the N-Gain analysis, indicating that most students achieved scores within the medium to high categories. In addition, Table 11 presents the distribution of improvements across specific indicators of argumentation skills, including claim construction, evidence use, counterargument, and rebuttal.

Table 9. Average score of scientific argumentation skills in experimental and control groups (pretest and posttest).

Meeting	N	Pre-test				Post-test			
		Control		Experiment		Control		Experiment	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I	25	19.57	19.88	24.00	24.22	36.96	21.15	46.00	24.66
II	25	2.17	7.20	7.00	11.46	6.52	11.22	49.00	24.45
III	25	8.70	23.37	8.00	11.90	13.04	27.04	47.00	23.18
IV	25	6.52	11.22	12.00	12.75	11.96	12.77	69.00	16.58
Average	25	9.24	15.42	12.75	15.08	17.12	18.05	52.75	22.22

Table 10. Results of prerequisite tests of normality and homogeneity for pretest and posttest data.

Prerequisite	Analysis	Initial data		Transformation Data		Data Reduction	
		Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Normality	Kolmogorov-Smirnov	0,000	0,004	0,001	0,000	0,000	0,91
	Shapiro-Wilk	0,000	0,003	0,001	0,000	0,000	0,90
Homogeneity ANOVA	One way	0,413	0,000	0,006	0,000	0,000	0,172

Table 11. Results of hypothesis testing on pretest and posttest scores of scientific argumentation skills.

Test	Analysis	df	Sig.(p)	Description
Pre-test	Mann Whitney	48	0,489	There is no significant difference in learning outcomes
Post-test	Uji T	38	< 0,001	There is a significant difference in learning outcomes

The effectiveness of BANDI was measured through pretest–posttest comparisons, N-Gain analysis, and hypothesis testing. The experimental group showed a significant improvement in posttest scores (52.75) compared to the control group (17.75), with N-Gain values categorized as moderate (0.3–0.7). In contrast, the control group remained in the low category. These results demonstrate that BANDI provides structured opportunities for students to practice making claims, using data as evidence, and constructing justifications, thereby enhancing scientific argumentation skills.

Compared to previous studies, the results of this research are consistent with findings that STEM-based instruction can significantly enhance students' scientific argumentation skills and scientific reasoning abilities (Muspiroh *et al.*, 2024). Project-based learning models within STEM contexts have been shown to improve both scientific reasoning and argumentation performance, with students in these programs outperforming those in conventional classrooms (Ayuni *et al.*, 2022). The integration of argumentation-based STEM activities has also been found to positively impact students' ongoing motivation and engagement in STEM learning (Dönmez *et al.*, 2022). Furthermore, the use of argument-driven inquiry models in STEM education has been demonstrated to promote significant gains in students' scientific reasoning patterns, particularly in areas such as correlational, probabilistic, and proportional reasoning (Atqiya *et al.*, 2021).

Inquiry-based instructional models that emphasize the nature of science and argumentation have been validated as both feasible and practical for developing students' scientific argumentation abilities in science learning (Lestari *et al.*, 2024). Additionally, phenomenon-based and argument-driven inquiry approaches have been shown to produce moderate to large improvements in both argumentation and scientific reasoning, although students may still face challenges in associating phenomena with appropriate scientific principles (Syarqiy *et al.*, 2023). Despite these positive outcomes, some studies note that the level of improvement in scientific reasoning and argumentation is often moderate, suggesting that longer-term application or more intensive scaffolding may be necessary to achieve higher effectiveness (Koes-H & Putri, 2021).

Indicator-Based Analysis of Scientific Argumentation

A more detailed analysis was carried out to examine student achievement on each indicator of scientific argumentation, namely claims, justification, support, and rebuttal. Table 3 shows that the data indicator achieved the highest N-Gain value (categorized as high), while the support indicator obtained the lowest (categorized as low).

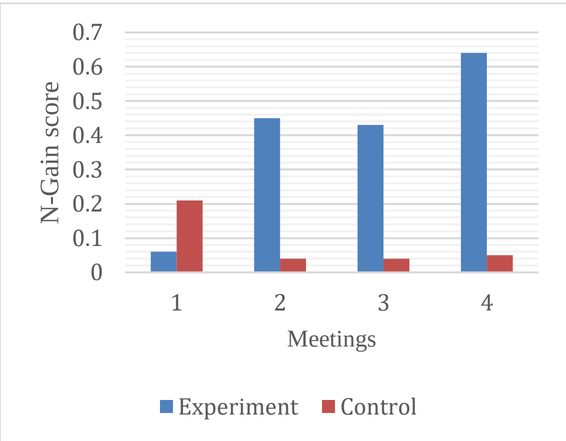

Figure 1 N-gain Analysis Results Scientific argumentation skills

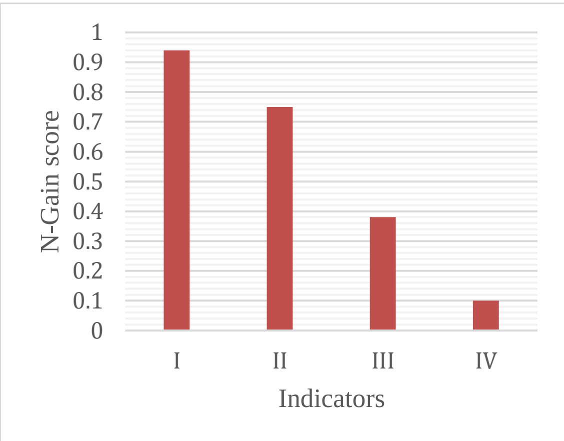

Figure 2 N-Gain analysis of scientific argumentation skills in terms of each indicator

Description: 0.0 = stable; 0.0< & < 0.30 = low; 0.30< & < 0.70 = Medium; 0.70-1.00 = High

Analysis of each indicator revealed that the data indicator achieved the highest N-Gain (high category), while the support indicator was the lowest (low category). This suggests that BANDI effectively trains students to gather and use data but still faces challenges in helping them integrate multiple concepts for support. Students were comfortable stating claims and using evidence but struggled to combine reasoning chains for more complex justifications. This finding highlights a common difficulty in scientific argumentation, where higher-order indicators demand more cognitive effort and abstract thinking.

The pattern observed in this study is consistent with previous research indicating that support indicators requiring the synthesis of diverse knowledge are among the most challenging aspects of argumentation for students to master (Yulianing *et al*., 2023; Boğar, 2019). Unlike earlier studies, however, the BANDI model demonstrated strong performance in data and justification indicators, suggesting that its design effectively supports the initial stages of constructing arguments (Hefter *et al*., 2014; Kuhn & Udell, 2003). This finding implies that BANDI is particularly effective for building foundational argumentation skills, such as formulating claims and providing justifications, but is less optimal for fostering advanced integration abilities like synthesizing multiple sources or constructing rebuttals (Mateos *et al*., 2018; Ybyrayeva *et al*., 2023).

Given these results, it is important to note that interventions which include explicit strategy instruction and structured reflection have been shown to improve students' ability to integrate conflicting information and develop higher-level argumentation skills (Mateos *et al*., 2018; Iordanou, 2022). Therefore, future development of BANDI should focus on incorporating scaffolding strategies, such as structured prompts, model examples, and opportunities for reflective practice, to help students advance in support and rebuttal indicators (Iordanou, 2022; Iordanou & Rapanta, 2021).

Educational Implications for 21st-Century Competencies

BANDI's integration of NGSS dimensions, discovery learning, and game mechanics aligns with research showing that STEM-based, student-centered approaches are effective in developing 21st-century skills such as critical thinking, collaboration, communication, and creativity (Alali, 2024; Stehle & Peters-Burton, 2019). Project-oriented and problem-based STEM models have been shown to significantly enhance these competencies by immersing students in authentic, real-life problem-solving experiences (Alali, 2024; Husin *et al*., 2016). Similarly, inclusive STEM high schools and digital classroom models foster environments that support the growth of both cognitive and noncognitive 21st-century skills, though sustained and well-designed instruction is needed for higher-level skill development (Stehle & Peters-Burton, 2019; Zainil *et al*., 2022).

The use of game elements in BANDI is supported by evidence that motivational and interactive features can further boost student engagement and learning outcomes, especially when combined with inquiry-based and NGSS-aligned practices (Mudinillah *et al*., 2024; Amelia & Santoso, 2021). While many NGSS- or discovery-based models focus on reasoning and conceptual understanding, they often lack the motivational design found in game-based approaches; conversely, game-based models may not guarantee deep conceptual learning (Amelia & Santoso, 2021; Hakim *et al*., 2019). BANDI's novelty lies in bridging this gap, simultaneously addressing both cognitive and affective domains.

Given its holistic design, BANDI can be considered a comprehensive instructional model for improving scientific argumentation and 21st-century competencies (Alali, 2024; Wardana *et al*., 2024; Penelitian *et al*., 2023). Policymakers and educators are encouraged to adopt and adapt BANDI in science classrooms as a strategic effort to prepare students for the demands of the modern world, equipping them with essential reasoning, communication, and problem-solving skills.

Conclusion

The study concluded that BANDI has a good capacity to support scientific argumentation skill-oriented learning. This capacity is seen both in terms of practicality and effectiveness. The practicality can be seen through observation of learning implementation in the highly implemented category and with student and teacher responses in the highly practical category. The effectiveness can be seen through the N-Gain where the majority of experimental group scores are in the moderately effective category. Furthermore, hypothesis testing also proves the effectiveness of BANDI with inferential that showed there are significant differences in learning outcomes of scientific argumentation skills between the control group and experimental group, where the experimental group has a much higher average score.

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Author Contributions

Conceptualization, L. Hasan N. Z., A. Wahab Jufri, and Prapti Sedijani; methodology, L. Hasan N. Z., A. Wahab Jufri, and Prapti Sedijani; software, L. Hasan N. Z., A. Wahab Jufri, and Prapti Sedijani; validation, I. P. Artayasa, A. Syukur, and P. Sedijani; formal analysis, L. Hasan N. Z.; investigation, L. Hasan N. Z.; resources, L. Hasan N. Z.; data curation, L. Hasan N. Z., A. Wahab Jufri, and Prapti Sedijani; writing—original draft preparation, L. Hasan N. Z.; writing—review and editing, L. Hasan N. Z., A. Wahab Jufri, and Prapti Sedijani; visualization, L. Hasan N. Z., A. Wahab Jufri, and Prapti Sedijani; supervision, A. Wahab Jufri and Prapti Sedijani; project administration, L. Hasan N. Z. All authors have read and agreed to the published version of the manuscript.

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