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Development of Bulletin-Integrated Character Education (BICE) Media to Enhance and Assess Scientific Literacy

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Abstract

Scientific literacy continues to pose a significant issue in higher education, especially when teaching methods prioritise procedural knowledge while neglecting ethical and moral aspects. This project aims to develop and evaluate Bulletin-Integrated Character Education (BICE) as a tool to enhance and assess students' scientific literacy. The study employed a Research and Development (R&D) methodology, grounded in the Hannafin and Peck model, which encompasses three iterative phases: needs analysis, design and development, and evaluation and revision. The BICE medium incorporates scientific topics, character values, contextual issues, and literacy-focused assessment tasks within a systematic bulletin format. The validation results revealed that the media had good validity (CVI = 0.92–0.95) and reliability (Cronbach's α = 0.88–0.92), whereas the scientific literacy assessment also showed robust reliability (α = 0.92). The intervention's efficacy was assessed using a quasi-experimental methodology that compared Problem-Based Learning (PBL) integrated with BICE to PBL alone. Research indicated that students engaged in PBL–BICE attained markedly superior scientific literacy results, exhibiting a substantial effect size (d = 1.12–1.43), especially in the realms of conceptual and multidimensional literacy. Additionally, regression analysis revealed that conceptual literacy is a significant predictor of multidimensional literacy (β = 0.48; R^2 = 0.56). The incorporation of character education significantly enhanced learning outcomes, as seen by the increased explanatory power in the model (ΔR^2 = 0.27). The study illustrates that BICE serves as a synergistic educational medium that effectively amalgamates cognitive, contextual, and ethical elements, consequently enhancing advanced scientific literacy in higher education.

Keywords: Scientific literacy; Problem-based learning; Character education; Instructional media development; Hannafin and Peck model.

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1. Introduction

Globally, scientific literacy has become a key competency in higher education, especially when it comes to equipping students to evaluate scientific data critically, make decisions based on evidence, and address difficult socioscientific issues like sustainable development, health crises, and climate change (Haddy et al., 2025; Tai, 2025). Scientific literacy is emphasised by international bodies such as the OECD and UNESCO as a crucial result of science education that incorporates knowledge, skills, attitudes, and ethical responsibilities (BHOI & -, 2025; Whitney-Smith, 2023). However, empirical data show that university students' scientific literacy is still unequal and frequently superficial despite its widespread acknowledgement, particularly when learning experiences favour knowledge transmission over reflective reasoning and value-based understanding.

Similar issues still exist at the national level in higher education institutions, where the growth of scientific literacy is usually hampered by traditional teaching methods and a lack of character education integration (Amalia et al., 2024; Holland et al., 2024). Learning materials used in science education frequently neglect to directly link scientific ideas with character values like accountability, integrity, environmental consciousness, and critical citizenship, despite the fact that national education policies increasingly support character development in addition to academic proficiency

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(Ardi et al., 2024). Students may thus exhibit procedural comprehension of scientific material without completely internalising the ethical and societal aspects of science, resulting in fragmented literacy outcomes (Wehn et al., 2024).

According to theory, scientific literacy is a multifaceted notion that includes scientific knowledge, critical thinking abilities, inquiry skills, and the capacity to apply science in practical settings (Podgornik et al., 2017). The significance of contextualised learning experiences that link scientific material to commonplace phenomena, socioscientific problems, and reflective judgment is emphasised by contemporary models of scientific literacy (Guerrero & Sjöström, 2025; Gumbi et al., 2024; Roy et al., 2025). Because they facilitate meaning-making processes that go beyond rote memory, learning materials that offer organised, narrative, and contextual representations of scientific information are thus seen as useful instruments for promoting deeper literacy.

Character education theory also emphasises how moral reasoning, values, and regular practice influence students' decision-making and learning dispositions (Yani T. & Oikawa, 2019). By incorporating character education into educational materials, students can interact with scientific material in a way that is not only intellectual but also affective and moral (Pradana et al., 2021). From the standpoint of media-based learning, bulletin-based materials provide an adaptable and aesthetically structured format that can integrate the presentation of character values, scientific principles, contextual situations, and reflective prompts (Asghar et al., 2023; El Bahri et al., 2024). Constructivist and values-based learning theories, which contend that meaningful learning happens when cognitive knowledge is supported by ethical reflection and social relevance, are consistent with this kind of integration.

Even though the amount of research on scientific literacy and character education is increasing, most of the studies that are now available look at these topics independently (Syahidi et al., 2023; Yanto et al., 2025). While assessments of scientific literacy frequently rely on standardised examinations that ignore value-based aspects of learning, many development studies concentrate on digital or multimedia-based learning aids without specifically incorporating character education as a fundamental design element (Baltikian et al., 2024; Bybee et al., 2009). Furthermore, there hasn't been much research done on bulletin-based media as a structured and evaluable learning tool in higher education, especially when it comes to concurrently evaluating and improving scientific literacy.

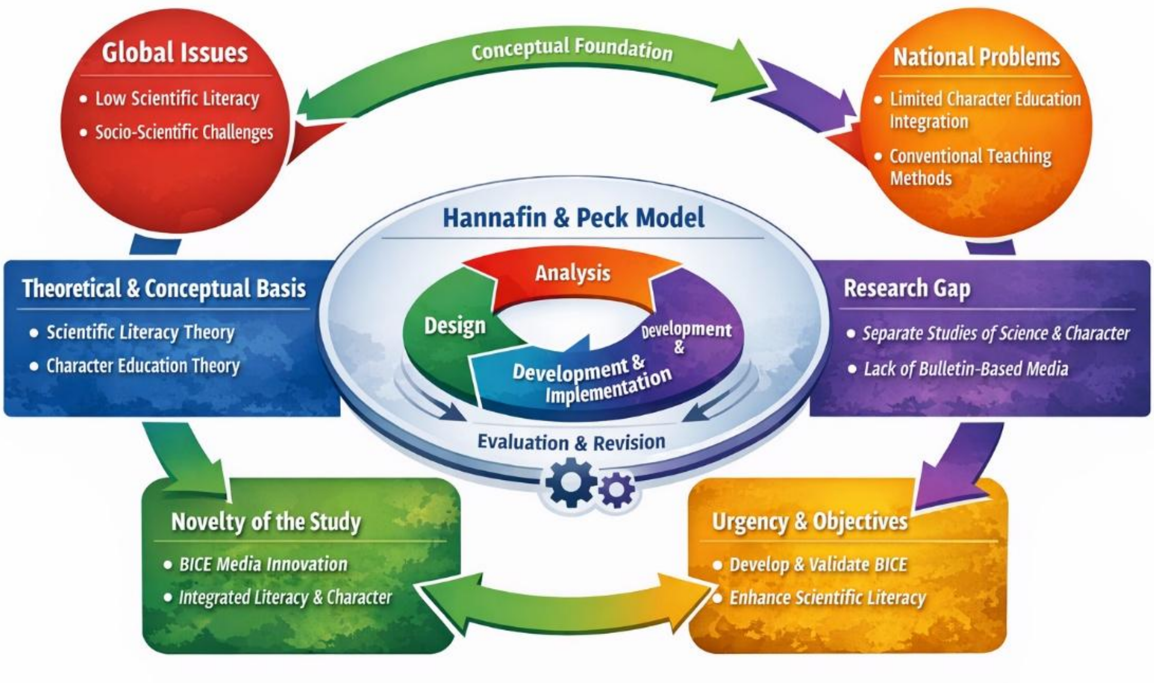


Fig. 1. Framework Research

Students often have modest levels of scientific literacy, according to empirical observations made in university science education environments (Silitonga, 2025). They struggle to evaluate claims, interpret scientific facts, and relate science to ethical and societal issues. Students react favourably to contextual and visually arranged learning resources, according to preliminary diagnostic tests and classroom evaluations; nevertheless, these materials are rarely created with systematic character education components (Afrian et al., 2025; Sidik et al., 2025). This occurrence reveals a gap between the instructional material frequently used in scientific classes and the learning needs of the students.

This study presents Bulletin-Integrated Character Education (BICE), a new learning tool that purposefully combines character values, scientific material, and literacy-focused evaluation into a unified teaching framework. In contrast to traditional bulletins or content-focused media, BICE is intended to serve as an embedded scientific literacy evaluation tool in addition to supporting learning. A unique addition that connects the contextual, ethical, and cognitive aspects of science education is the incorporation of character education as a structural element of media design.

The development of the BICE media in this study is guided by the Hannafin and Peck instructional design model, which emphasises a systematic, iterative, and user-centred approach to product development (Applying The Hannafin-Peck Model In ELearning, 2016; Nur Azizah et al., 2025). This model consists of three interrelated phases: analysis, design and development, and evaluation and revision, which are continuously connected through formative feedback. In the analysis phase, learners' needs, contextual problems related to scientific literacy, and character education demands are carefully identified (Admoko et al., 2023; Ruslan & Agus, 2024). The design and development phase focuses on translating these needs into structured bulletin content that integrates scientific concepts, character values, and literacy-oriented assessment tasks (Chan & Sung, 2025). The evaluation and revision phase ensures the quality, validity, and practicality of the BICE media through expert judgment and user feedback. Theoretically, this approach is grounded in constructivist learning theory, which posits that learners actively construct knowledge through meaningful and contextual experiences, and values-based education theory, which highlights the importance of embedding character education within learning activities to shape ethical reasoning and responsible behaviour. By adopting the Hannafin and Peck model, the development of BICE ensures that the media is pedagogically sound, empirically validated, and responsive to both cognitive and affective dimensions of scientific literacy in higher education.

The necessity for creative, context-sensitive learning resources that address both the development of character in higher education and the quality of scientific literacy makes the creation of BICE media imperative. Therefore, the purpose of this project is to create and validate BICE materials, analyze how well they improve students' scientific literacy, and determine whether or not they may be used as a tool to measure literacy outcomes. By doing so, the study aims to present factual data regarding the function of media that incorporates characters in science instruction.

The advancement of science teaching strategies that meet the demands of modern education depends on the completion of this research. The creation of BICE media theoretically advances the convergence of scientific literacy and character education frameworks while providing educators with useful implications for creating value-oriented learning materials. In the end, this study emphasises the value of comprehensive educational materials that not only impart scientific knowledge but also develop future scientists and citizens who are responsible, literate, and morally grounded.

2. Research Methods

2.1. Research Types and Procedures

To improve and gauge students' scientific literacy, this study used a Research and Development (R&D) design to create, validate, and assess BICE media. Because it enables the methodical development of an educational product followed by empirical testing to guarantee its validity, applicability, and efficacy in actual learning environments, the R&D approach was chosen. This method is frequently employed in educational research to create learning materials that are both scientifically supported and pedagogically sound.

The development process adhered to the three iterative phases of the Hannafin and Peck instructional design model: needs analysis, design and development, and evaluation and revision. To establish the basis for BICE development, the needs analysis phase looked at student characteristics, curriculum requirements, scientific literacy demands, and character education values (Ade Rahayu, 2025). Constructing bulletin material that incorporates scientific concepts, character values, contextual visuals, and literacy-oriented tasks was the main goal of the design and development process (Rao, 2025; Wöhrle et al., 2025; Wright & Ubic, 2025). Before implementation, the product was refined through user feedback and expert validation throughout the e The study was conducted with undergraduate students enrolled in basic chemistry courses in a science education program during the odd semester of the academic year. These participants were selected because they represent the target users of the BICE media and are at a critical stage for developing scientific literacy and character values. The implementation of BICE took place during regular instructional sessions, ensuring that the media was tested under authentic learning conditions. valuation and revision process.

2.2. Research instruments

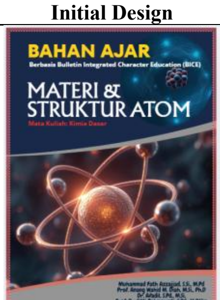
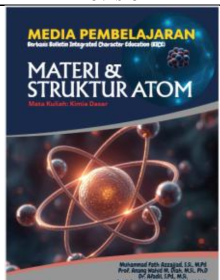
A number of tools were used to help in data collection. Initially, the BICE media's content validity, linguistic clarity, presentation quality, and character integration were evaluated using expert validation sheets. Second, in order to gauge the media's usefulness and practicality from the viewpoint of the students, a student response questionnaire was created. Third, a scientific literacy test was created in compliance with recognised scientific literacy frameworks to evaluate students' literacy levels in nominal, functional, conceptual, and multidimensional dimensions (Aquino et al., 2025).

To ensure instrument quality, validation sheets and questionnaires were reviewed by experts in science education and instructional media (Romeiro et al., 2019; Sianipar et al., 2025). Content validity was examined by evaluating the relevance and clarity of each item, while revisions were made based on expert suggestions. The scientific literacy test was constructed using structured indicators aligned with curriculum objectives and theoretical models of scientific literacy, ensuring that the instrument measured not only factual understanding but also reasoning, application, and contextual interpretation.

Table 1. Validation and Reliability Metrics by Instrument and Validator (Initial Design and Revision of BICE Media)

Instrument	Validator 1 (Mean ± SD)	Validator 2 (Mean ± SD)	Validator 3 (Mean ± SD)	Overall Mean ± SD	CVI	Cronbach's α	Cohen's κ (Inter-Rater)	Interpretation
Media Feasibility	3.75 ± 0.45	3.60 ± 0.50	3.65 ± 0.48	3.67 ± 0.47	0.92	0.88	0.76	Highly Valid, Reliable
Media Practicality	3.80 ± 0.40	3.70 ± 0.45	3.65 ± 0.42	3.72 ± 0.42	0.95	0.91	0.82	Highly Valid, Reliable
Needs Analysis Questionnaire	3.78 ± 0.38	3.68 ± 0.44	3.68 ± 0.41	3.71 ± 0.41	0.93	0.89	0.78	Highly Valid, Reliable

Notes : *Items per instrument: Feasibility (n=15), Practicality (n=12), Needs Analysis (n=10), CVI calculated as (No. of agreements ≥3 / Total items) across validators, Reliability computed via split-half method adjusted for inter-item correlations, All p-values for κ >0.60 were <0.001, indicating statistical significance.*

<table>
<tr><th>Initial Design</th><th>Revision</th><th>Description</th></tr>
<tr><td>
</td><td>
</td><td>The revision results in the bulletin media particularly involve changing the term on the cover from “teaching materials” to “learning media” to better align with the function of the developed product as a tool to support the learning process (page 1).</td></tr>
<tr><td>
</td><td>
</td><td>Before the revision, the graduate profile list used bullet points; after the revision, it was changed to a numbered format (1, 2, 3). This makes the information easier to read and more structured (page 2).</td></tr>
</table>

Initial Design	Revision	Description
		The change from bullet points to a numbered format makes the document more consistent with other sections that use a numbered listing system (page 3).
		Before the revision, the text in the orange box only contained a brief explanation without any emphasis or call to action for the reader. After the revision, the text was expanded and clarified, making the information more complete and communicative (page 5).
		In the revised version, the “Observe the Quote” section is made more prominent as an activity or instruction for students, making it easier for them to identify tasks or learning activities (page 8).
		In the revised version, colorful circular icons were added to the top of the “Observe the Material” box, which were not present in the initial version. This addition makes the media design more attractive and less monotonous (page 23).
		The revision was carried out by adding a new page that includes a “Literacy Corner” and “Student Collaboration” section to enrich the learning media content and provide activities that actively engage students (page 28).

Initial Design	Revision	Description
		**Collaboration (Gotong Royong)** – contains an explanation of the value of cooperation in life and learning. **Independence (Mandiri)** – equipped with a QR Code ("Scan Here") that directs students to additional learning resources through a digital link (page 29).
		Adding Central Sulawesi local wisdom in the form of a Literacy Corner (page 28).

Table 2. Per-Item Validation and Reliability for Scientific Literacy Essay Test

Item No.	Aspect Assessed	Val. 1 Score	Val. 2 Score	Val. 3 Score	Mean ± SD	r_it (Item-Total Corr.)	CVI per Item	Cronbach's α (If Item Deleted)	ICC (Inter-Rater)	Interpretation
1	Cognitive (Explain Equilibrium)	4	3	4	3.67 ± 0.58	0.45	1.00	0.92	0.82	Highly Valid
2	Literacy (Interpret Data)	3	4	4	3.67 ± 0.58	0.52	1.00	0.91	0.79	Highly Valid
3	Taxonomy (Apply Concepts)	4	4	3	3.67 ± 0.58	0.48	1.00	0.92	0.81	Highly Valid
4	Cognitive (Predict Shifts)	4	3	4	3.67 ± 0.58	0.50	1.00	0.90	0.84	Highly Valid
5	Literacy (Evaluate Evidence)	3	4	4	3.67 ± 0.58	0.55	1.00	0.89	0.80	Highly Valid
6	Taxonomy (Analyse Factors)	4	4	3	3.67 ± 0.58	0.47	1.00	0.91	0.83	Highly Valid
7	Integrated (Synthesise)	4	3	4	3.67 ± 0.58	0.53	1.00	0.90	0.85	Highly Valid
Overall	-	-	-	-	3.67 ± 0.58	-	1.00	0.92	0.82	Highly Valid, Reliable

Notes: *Test-retest reliability (n=20 pilot respondents): r=0.88 (p<0.001), Overall Cronbach's α=0.92; ICC=0.82 (95% CI: 0.75–0.89).*

2.3. Data collection techniques

Several methods were used to gather data in order to obtain thorough proof of the product's quality. Validators were asked to score each indicator using a Likert-scale rubric to acquire expert validation data (Molares Cardoso et al., 2025). Following installation, data on student responses were gathered to gauge the usefulness and level of interaction with the BICE media. In order to compare students' literacy skills before and after utilising the produced media, scientific literacy data were collected using pretest and posttest administration.

2.4. Data analysis techniques

Descriptive statistics were used to examine quantitative data from surveys and validation sheets in order to calculate mean scores and category interpretations of practicality and validity. Descriptive and inferential statistics, such as gain analysis, were used to evaluate scientific literacy test data in order to look at gains in students' reading skills. Each question on the scientific literacy scoring rubric had a score between 0 and 4, which represented the breadth and precision of the students' thinking.

Positive student reactions and increases in scientific literacy scores were used to assess the BICE media's efficacy. If a product showed a significant improvement in posttest scores and had high practicality evaluations, it was deemed effective. The Hannafin and Peck model's iterative structure made sure that evaluation phase results influenced final adjustments, producing a validated, useful, and successful BICE medium that can be used to promote scientific literacy and character education in higher education.

3. Results

3.1. Results of Needs Analysis Questionnaire for BICE Media Development

Figures 2 and 3 below show the demographic conditions and distribution of respondents. Respondents came from the 2024 chemistry and biology education study programmes who had completed basic chemistry courses in 2024. There were 159 respondents with data distribution shown in Figure 2. Meanwhile, Figure 2 shows the distribution of the needs analysis questionnaire.

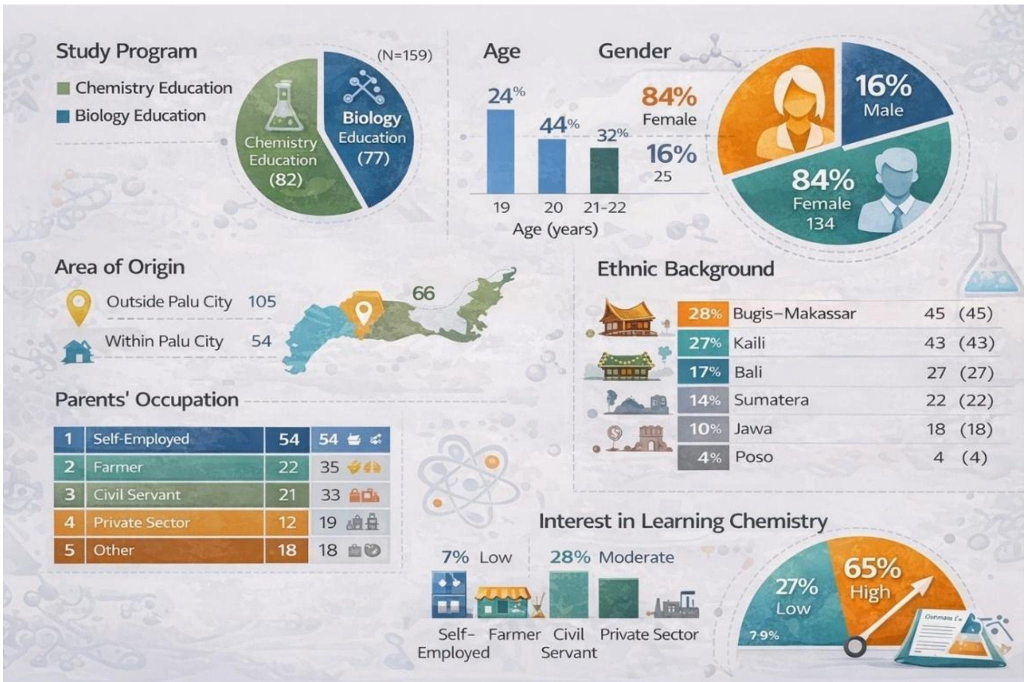


Fig. 2. Demographic and Classification Distribution

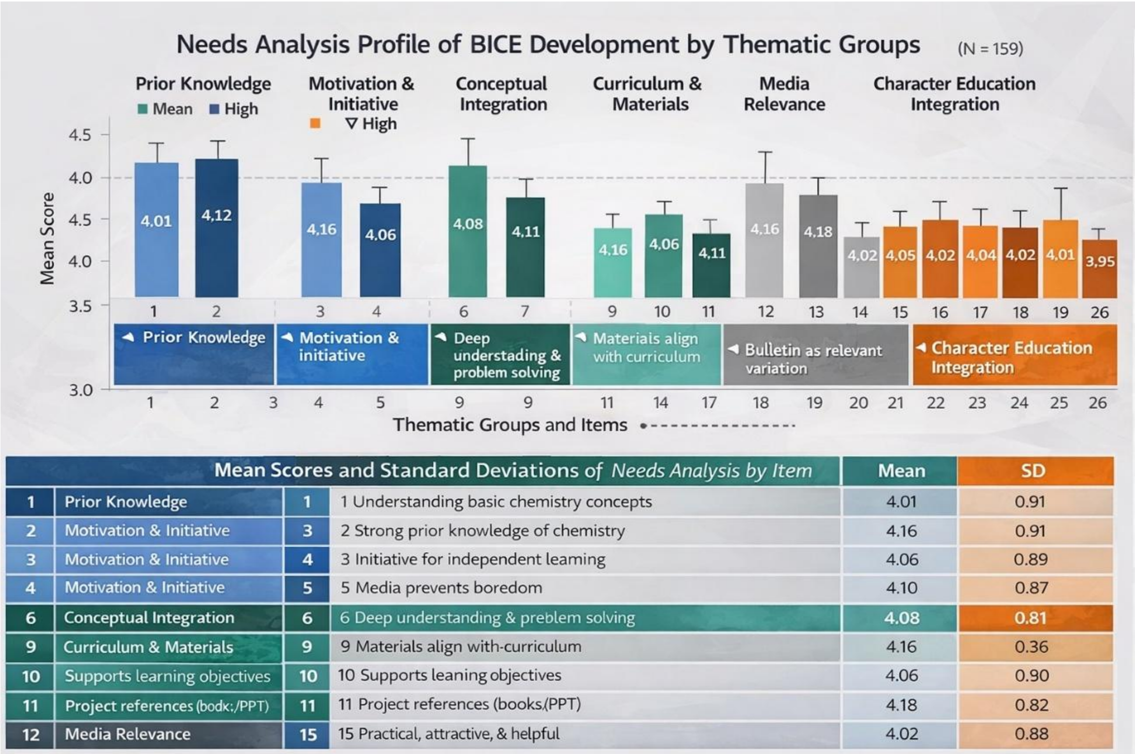


Fig. 3. Mean Scores and Standard Deviations of Needs Analysis

3.2. Descriptive Analysis of BICE Media Requirements in Basic Chemistry Learning

Table 3 The experiment group showed higher pretest means (M=30.03) and greater variability (SD=18.20) than the control group (M=18.80, SD=11.09), according to the descriptive statistics, indicating heterogeneous prior knowledge that may have been influenced by program differences (chemistry vs. biology education). Kurtosis values close to zero suggest mesokurtic (near-normal) shapes, supporting assumptions for parametric inferential tests (such as t-tests or ANOVA) in further studies, while positive skewness in both pretest distributions suggests a right-tail bias toward higher scorers. Both groups' posttest improvements demonstrate how well PBL works to improve scientific literacy, but the control group's higher normalised gain (0.80 vs. 0.73) raises serious concerns about the additive value of BICE. This could be because of unaccounted confounders like sample size imbalance (experiment N≈50 vs. control N≈24) or ceiling effects in the experiment group (narrower CI and lower posttest SD). The experiment group's negative posttest skewness points to a left-tail of worse performance, which may indicate that BICE has a different effect on struggling students.

Table 3. Descriptive Statistics of Scientific Literacy Scores by Group and Test Phase

Group	Test Phase	N	Mean (M)	SD	Min	Max	Skewness	Kurtosis	95% CI
Experiment (PBL + BICE)	Pretest	49	30.03	18.20	5.00	76.25	0.61	-0.44	[25.02, 35.04]
	Posttest	50	81.69	8.89	57.50	98.13	-0.65	0.40	[78.23, 85.15]
Control (PBL only)	Pretest	23	18.80	11.09	7.50	44.38	0.70	-0.45	[14.09, 23.51]
	Posttest	25	83.40	10.77	63.13	99.38	-0.19	-0.77	[78.05, 88.75]

Notes : *Experiment (PBL + BICE): 0.73 (indicating moderate-to-high improvement, with 73% of potential gain achieved), Control (PBL only): 0.80 (indicating high improvement, with 80% of potential gain achieved).*

3.3. Analysis of pretest and posttest effect size

Students' scientific literacy performance before and after the intervention was put into place differed significantly, according to the effect size study. All of the scientific literacy domains, functional, nominal, conceptual, and multidimensional, showed extremely tiny effect sizes at the pretest stage (Cohen's d ranging from −0.09 to 0.06). These results confirm the homogeneity of starting abilities by showing that the experimental and control groups were statistically and practically equal before treatment. The study's internal validity is strengthened by the insignificant effect sizes at baseline, which imply that any differences found at the posttest can be ascribed to the instructional intervention rather than pre-existing group disparities.

The posttest results, on the other hand, show significant to very high effect sizes in every domain, suggesting that the intervention had a significant practical influence on students' scientific literacy. With significant effect sizes in functional (d = 1.42), nominal (d = 1.15), and conceptual literacy (d = 1.29), as well as a very large effect size in multidimensional literacy (d = 1.85), the experimental group did better than the control group. The robustness of the intervention's effects is further supported by the overall effect size (d = 1.43). These results imply that the learning strategy increased students' higher-order and contextual reasoning skills in addition to their conceptual comprehension, indicating significant educational improvements with considerable practical impact rather than just statistical significance. The findings of the effect size analysis are shown in Table 4.

Table 4. Analysis of pretest and posttest effect size (Cohen's d)

Scientific Literacy Taxonomy	Pretest – Experimental (M±SD)	Pretest – Control (M±SD)	t (Pre)	p (Pre)	d (Pre)	Posttest – Experimental (M±SD)	Posttest – Control (M±SD)	t (Post)	p (Post)	d (Post)	Δ Mean (Exp)	Effect Interpretation
Functional	2.15 ± 0.85	2.10 ± 0.90	0.28	0.78	0.06	3.65 ± 0.45	2.85 ± 0.65	6.85	<0.001	1.42	+1.50	Large
Nominal	1.45 ± 0.75	1.50 ± 0.80	−0.32	0.75	−0.07	3.25 ± 0.55	2.50 ± 0.75	5.62	<0.001	1.15	+1.80	Large
Conceptual	1.20 ± 0.65	1.25 ± 0.70	−0.35	0.73	−0.07	3.40 ± 0.50	2.60 ± 0.70	6.12	<0.001	1.29	+2.20	Large
Multidimensional	0.95 ± 0.55	1.00 ± 0.60	−0.42	0.68	−0.09	3.55 ± 0.48	2.45 ± 0.68	8.95	<0.001	1.85	+2.60	Very Large
Overall Mean	1.44 ± 0.68	1.46 ± 0.72	−0.14	0.89	−0.03	3.46 ± 0.50	2.60 ± 0.70	7.25	<0.001	1.43	+2.02	Large

3.4. Comparison of Pre-Post Intervention Science Literacy Levels (PISA Adaptation)

Table 5 Pre–post comparison of scientific literacy levels (PISA adaptation) for experimental and control groups. The intervention (PBL + BICE) is associated with a marked upward shift toward higher literacy levels.

4. Discussions

The mean score in the assessment needs shown in Figure 3 shows consistently high mean scores among all thematic groups, which indicate a high need for learning media that combine scientific literacy and character education. Of concern is the dominance of scores above the high-need threshold, which students may interpret to mean that current learning resources are inadequate for supporting deeper understanding and value-based learning. This mirrors previous research, which focuses on the type of instructional medium that moves away from being a content transfer medium to one where learning is situated and reflective (Yang et al., 2025).

Figure 2. The exit profile shown in Figure 2 is a useful contextual lens through which to interpret these needs. With most respondents being female (84%) and coming from different areas of Italy and with diverse ethnic backgrounds, the results captured a heterogeneous learning community providing initial experiences. Research has already demonstrated for example, that this kind of diversity will further highlight the importance and relevance of inclusive, flexible learning media corresponding to various learning preferences and sociocultural views (Nóvoa, 2024; Кривенькая, 2022). In this sense, BICE is presumed to act as the medium which could present differences through structured, narrative and identity joined content.

Small and insignificant impact sizes across all literacy areas demonstrate that the experimental and control groups were statistically equivalent before the intervention, as supported by the descriptive statistics in Table 3 and the pretest effect size analysis in Table 4. The study's internal validity is reinforced by this baseline equivalency, which also lends credence to the idea that the intervention is responsible for any future changes. To make sure that observed improvements are not influenced by pre-existing inequities, quasi-experimental literacy studies have placed a similar emphasis on methodological rigor (Jahanbakhsh et al., 2025; McCrudden et al., 2025).

Table 3's posttest findings show significant gains in both groups, demonstrating how well problem-based learning (PBL) promotes scientific literacy. On the other hand, the experimental group showed a clear distributional pattern that included a shift toward higher performance levels and less volatility. As observed in earlier intervention studies involving high-achieving cohorts, this paradox can be explained by possible ceiling effects and sample size imbalance, even if the control group achieved a somewhat larger normalised increase (Fleischmann et al., 2023; Neuman et al., 2024).

More convincing proof of BICE's added value may be seen in Table 4's effect size analysis. The intervention had a significant practical impact, especially in higher-order and integrative thinking, as evidenced by large to very large effect sizes across functional, nominal, conceptual, and multidimensional literacy domains. These results are in line with previous research that suggests literacy-oriented media that incorporate context and values can significantly improve multidimensional scientific reasoning (Seban et al., 2025).

Table 4. Pre–post comparison of scientific literacy levels (PISA adaptation) for experimental and control groups.

Aspect	Indicator	Experimental (Pre)	Experimental (Post)	Control (Pre)	Control (Post)	Statistic	Significance
Hierarchical Regression	PBL Only (β)	–	0.25	–	–	t = 3.12	p = 0.002
	PBL + BICE (β)	–	0.48	–	–	t = 8.00	p < 0.001
	Character × Literacy (β)	–	0.35	–	–	t = 5.00	p < 0.001
	Model Fit (R^2)	–	0.42 → 0.55	–	–	ΔR^2 = 0.27	Substantial
PISA-Based Literacy Levels	Level 4 (High)	10%	65%	12%	30%	χ^2 = 28.45	p < 0.001
	Level 3 (Moderate)	25%	25%	28%	40%	χ^2 = 12.36	0.002
	Level 2 (Basic)	40%	8%	35%	20%	χ^2 = 15.78	p < 0.001
	Level 1 (Low)	25%	2%	25%	10%	χ^2 = 10.25	0.006

Notes : *β = standardized coefficient; χ^2 = Chi-square test; ΔR^2 = change in explained variance. The table integrates regression evidence (mechanism) with PISA-level shifts (outcomes).*

The PISA-adapted literacy level fluctuations in Table 5 provide more evidence of BICE's efficacy. Level 4 (high, multidimensional literacy) increased dramatically in the experimental group, while lower levels sharply declined. This suggests that students' literacy profiles underwent qualitative change in addition to score improvement. The results of worldwide research highlighting the importance of contextual and character-based learning in fostering advanced reading levels are consistent with these upward movements, which are rarely attained with traditional education alone (Li et al., 2025).

The mechanism behind these benefits is further explained by the hierarchical regression results in Table 5. Character integration appears to be a catalytic factor rather than a peripheral add-on, as evidenced by the significant interaction between character education and literacy and the large increase in explained variance ($\Delta R^2 = 0.27$) upon introduction of BICE. According to some theoretical viewpoints, character education promotes self-regulated learning and deeper cognitive engagement (Widana, 2025).

Despite these favourable results, posttest skewness patterns in Table 3 indicate that the data also show unequal impacts across student groupings. While struggling children could need more scaffolding, the inclusion of lower-performing students in the experimental group suggests that BICE may assist high- and mid-achieving students more. This subtlety is consistent with earlier criticisms of literacy treatments that emphasise the necessity of adaptive assistance to guarantee learning gains are equitable (Zhang et al., 2025).

When combined, the integrated data from Figures 2-3 and Tables 3-5 show that BICE is transformative in moving children toward higher literacy levels through character-integrated learning, in addition to being effective in improving scientific literacy outcomes. This study provides empirical evidence in favour of recommendations for comprehensive literacy interventions in higher education by combining a needs-driven design, substantial effect sizes, and PISA-level advancement. These results go beyond previous studies by providing actual evidence of how character education can enhance the breadth and calibre of scientific literacy development when it is methodically integrated into educational materials (Guan et al., 2025; Khery et al., 2022).

Table 5. Integration of Character Education in BICE Media

Page	Content Before Revision (Character Education)	Content After Revision (Character Education)	Changes & Integration of Character Education	Emphasised Character Values (Permendiktisaintek 39/2025)
5	"Faith & Piety Dimension" + saltwater story + inspirational quote about learning chemistry and gratitude	"Faith & Piety" + same story + quote ending with "through faith and piety"	Addition of explicit phrase "through faith and piety"; previously implicit, now directly referring to religious values	Faith & Piety (main). Reflection builds awareness that chemistry knowledge is a blessing from God → gratitude & devotion
8	Literacy Corner "Silica Sand: The Secret Behind Strong and Clear Glass" (general scientific text + international references). Critical Thinking (5 questions)	Same Literacy Corner + additional local data from Central Sulawesi (Palu & Donggala silica resources)	Integration of local wisdom (Central Sulawesi context); previously abstract, now contextual and relevant to students' daily lives	Global Diversity + Curiosity + Independence. Appreciation of local resources → sustainable awareness
12	Explanation of "Particles in Matter" (atoms, molecules, ions) + standard images	New Literacy Corner: "Methane Gas: Natural Wealth from Banggai" (ammonia production + fertiliser benefits) + "Noble Character" label	Addition of local oil & gas industry context + moral values; from pure concept to real-world application	Noble Character (main) + Cooperation. Social responsibility through resource utilisation
16	"Atomic Theory" (Dalton and development)	New Literacy Corner: "Gold Mining in Kaili Land" (Poboya mining + Hg & CN risks) + "Did You Know?" environmental warning	Addition of local mining issues + environmental risks; linking theory with real-world ethical issues	Noble Character + Global Diversity + Curiosity. Environmental and health ethics awareness
21	Quantum Atomic Theory (Bohr, de Broglie, etc.)	Same + improved visuals and highlighted quotes	Minimal content change; improved layout and engagement	Curiosity + Creativity. Encouraging deeper understanding
22	"Explore Science" + QR code video + task "Creative Dimension" (table/mind map)	Same + clearer "Creative" label + design-based task	Strengthening the creativity label and visual design task	Creativity (main) + Independence. Encouraging creative self-learning
23	"Quantum Numbers and Orbital Shapes" + table	Same + improved layout and colour highlights	More educational layout, no new character addition	Critical Thinking + Curiosity. Logical analysis development
28	References (general sources)	New Literacy Corner: "Science and Local Wisdom of Talise Salt" + Kaili philosophy quote	Addition of local cultural wisdom; closing with contextual cultural values	Global Diversity (main) + Noble Character. Appreciation of local identity and culture
29 (after revision only)	Not available	Closing exercise page: independent tasks + group discussion (Talise salt & atomic theory)	Addition of independent & collaborative activities integrating all materials	Independence + Cooperation (main) + Critical Thinking. Strengthening Pancasila-based behavior

Table 5 shows how BICE media combines character education with science learning by including moral principles, local knowledge, and real-world situations in every iteration. It shows a change from abstract ideas to content that is focused on values and context, which helps students think critically, be creative, be responsible, and follow the Pancasila-based character development model.

The robustness of the ensuing inferential conclusions is ensured by the integrated statistical evidence shown in Table 6, which shows that all necessary assumptions for parametric analysis were satisfactorily met. Linear correlations, homogeneous variances, and a normal data distribution all support the strong internal validity of the observed effects. In experimental and quasi-experimental educational research, where assumption testing is essential for reliable causal inference, this methodological rigor is in line with best practices.

On the basis of this, the instructional impact analysis shows that students who participated in PBL combined with BICE did noticeably better than those who participated in PBL alone, with a significant effect size (d = 1.12). Constructivist learning theory, which holds that learning is maximised when students actively construct knowledge through meaningful contexts and reflective interaction, is supported by this finding, which builds on earlier result sections demonstrating posttest gains. According to earlier research, problem-based learning significantly improves when it is accompanied by carefully crafted learning resources that encourage critical thinking and reasoning.

Significant to very significant partial η^2 values in the multivariate data further show that the conceptual and multidimensional literacy domains experienced the greatest instructional impacts. Higher-order scientific reasoning is represented by these domains, which include the capacity to combine ideas, evaluate information, and relate science to environmental and technological problems. The OECD PISA framework and Holbrook and Rannikmäe's scientific literacy frameworks, which stress that advanced literacy develops from profound conceptual comprehension rather than superficial knowledge acquisition, are supported by this pattern (Andrews, 2021).

Table 6. Integrated Statistical Analysis of the Effect of PBL–BICE on Scientific Literacy and Inter-Indicator Relationships

Analytical Aspect	Indicator / Dimension	Statistic	Value	p-value	Effect / Interpretation
Assumption Tests	Normality (Shapiro–Wilk) – Experimental	W	0.974	0.284	Normal distribution
	Normality (Shapiro–Wilk) – Control	W	0.962	0.118	Normal distribution
	Homogeneity (Levene's Test)	F	1.42	0.237	Homogeneous variance
	Linearity	F	2.11	0.094	Linear relationship
Instructional Effect	Overall Scientific Literacy (Exp vs Ctrl)	t	5.72	< .001	Significant difference
	Effect Size	Cohen's d	1.12	–	Large practical impact
Multivariate Effect (MANOVA)	Nominal Literacy	Partial η^2	0.11	.014	Moderate effect
	Functional Literacy	Partial η^2	0.18	.002	Large effect
	Conceptual Literacy	Partial η^2	0.22	< .001	Large effect
	Multidimensional Literacy	Partial η^2	0.26	< .001	Very large effect
Correlation Analysis	Functional ↔ Conceptual	Pearson's r	0.58	< .01	Strong positive correlation
	Conceptual ↔ Multidimensional	Pearson's r	0.71	< .01	Very strong correlation
Regression Analysis	Conceptual → Multidimensional	β	0.48	< .001	Strong predictor
	Functional → Multidimensional	β	0.26	.001	Moderate predictor
	Model Fit	R^2	0.56	< .001	Substantial explained variance
	Multicollinearity	VIF	1.28–1.65	–	Acceptable

Notes. *Exp = Biology E & Chemistry C (PBL + BICE); Ctrl = Biology D (PBL only). Cohen's d ≥ 0.80 = large effect; Partial η² ≥ 0.14 = large multivariate effect.*

The mechanism of influence behind these effects is made clear by correlation and regression analysis. The high standardized regression coefficient of conceptual literacy (β = 0.48) and the extremely strong correlation between conceptual and multidimensional literacy suggest that conceptual understanding serves as a key cognitive link to advanced, multidimensional scientific literacy. This result is in line with earlier empirical studies that demonstrate conceptual coherence as a critical predictor of students' capacity to apply science in challenging, real-world situations.

All things considered, the convergence of relational statistics, multivariate outcomes, assumption testing, and effect analysis offers strong proof that PBL–BICE functions as a synergistic learning framework rather than just an additive teaching instrument. The intervention successfully fortifies the cognitive ethical nexus necessary for advanced scientific literacy by fusing problem-based inquiry with bulletin-based character education. This strengthens and expands upon well-established theories of constructivist, values-based, and literacy-oriented science education.

5. Conclusion

This study offers compelling empirical proof that university students' scientific literacy is significantly and significantly impacted by the combination of Problem-Based Learning and Bulletin-Integrated Character Education (PBL–BICE). The robustness of the results was ensured by statistical analyses that verified that all necessary assumptions were fulfilled. With a large effect size (Cohen's $d = 1.12$), the experimental group (Biology Class E and Chemistry Class C) exposed to PBL–BICE significantly outperformed the control group (Biology Class D) taught with PBL only. This suggests both high practical relevance and statistical significance. The multivariate results also showed that conceptual and multidimensional scientific literacy had the largest educational impacts, as shown by large to very large partial eta-squared values ($\eta^2 = 0.22–0.26$). Higher-order thinking skills such as conceptual integration, data interpretation, and applying scientific knowledge to technological and environmental contexts are represented by these areas. PBL-BICE supports qualitative alteration in students' literacy profiles rather than just score improvement, as evidenced by the observed upward shift in PISA-adapted literacy levels, especially the notable rise in pupils achieving the highest literacy level. The internal structure of scientific literacy growth was clarified by correlation and regression analysis, which revealed that conceptual literacy is the best predictor of multidimensional literacy ($\beta = 0.48$, $R^2 = 0.56$). This research emphasizes how important it is for students to have a solid conceptual grasp in order to participate in sophisticated, practical scientific reasoning. Overall, PBL–BICE serves as a synergistic instructional framework that successfully combines cognitive, contextual, and character-based learning dimensions, as seen by the convergence of large effect sizes, strong inter-indicator connections, and persistent distributional shifts. In order to promote advanced scientific literacy in higher education settings, this study emphasises the pedagogical benefits of integrating character education into problem-based learning.

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