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Innovative project design-based learning: Enhancing students' critical thinking skills and sciencepreneurship for sustainable science education in junior high school

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Abstract: Education in the era of the Industrial Revolution 4.0 is required to equip students with 21st-century competencies, including critical thinking skills and sciencepreneurship. This study aims to develop an innovative IPDBL learning model that is effective in enhancing students' critical thinking skills and sciencepreneurship. This study employed educational development research based on McKenney's development model. A total of 99 eighth-grade students at the Indonesian School of Kuala Lumpur, Malaysia, participated in this study, divided into one control class (n = 30) and three experimental classes, each comprising 23 students. Data were collected through expert validation and tests of critical thinking skills (CTS) and sciencepreneurship. The obtained data were analyzed using Aiken's V, percentage of agreement (PA), N-gain score, and Kruskal–Wallis tests. The results showed that the IPDBL learning model and its teaching materials (lesson plans, student books, student worksheets, CTS test, and sciencepreneurship test) were valid and reliable. Based on the N-gain scores and Kruskal–Wallis tests, it can be concluded that the IPDBL learning model was very effective in improving students' CTS and sciencepreneurship. The implication of this study is that the IPDBL learning model can be considered an alternative innovative approach for sustainable science learning.
Keywords: *Critical thinking skills, Innovative project design-based learning (IPDBL), Sciencepreneurship.*

1. Introduction

Education in the era of the industrial revolution 4.0 increasingly emphasizes equipping students with essential skills to face 21st-century challenges, such as critical thinking, creativity, collaboration, and communication [1, 2]. Critical thinking is one of the most important 21st-century competencies to develop, as it enables students to critically examine information, evaluate evidence, and produce well-reasoned decisions [3, 4]. In science education, the development of this skill (CTS) is closely related to scientific literacy, problem-solving skills, and informed decision-making in real-life situations [5, 6]. However, the 2018 PISA results indicate that Indonesian students continue to demonstrate relatively low performance in tasks requiring critical thinking skills. Although there was a slight improvement in 2022, overall performance continued to decline [7, 8]. These findings suggest that continuous improvement in the quality of science learning is essential to facilitate learning activities that genuinely challenge and develop students' thinking skills.

In addition to critical thinking skills, today's education is required to equip students with an entrepreneurial spirit and guide them to innovate and create solutions to real-world problems [9]. Sciencepreneurship has emerged as an approach that integrates entrepreneurship into science learning, enabling students to generate innovative solutions. Through sciencepreneurship, science is not only

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learned as theoretical knowledge but also applied to produce products or solutions with practical, economic, and social value [10, 11].

Based on the results of preliminary research conducted at the Indonesian School in Kuala Lumpur, Malaysia, only a small proportion of students (17.4%) were found to consistently demonstrate strong critical thinking skills [12]. This finding indicates the need for a learning model that actively engages students and demands more than merely memorizing subject content. Among existing learning models, Project-Based Learning (PjBL) has the potential to develop students' critical thinking skills and sciencepreneurship because it encourages inquiry, collaboration, and problem-solving through meaningful tasks [13, 14].

However, PjBL still has limitations in implementation because it often focuses more on project completion than on fostering entrepreneurial thinking. The integration of the Engineering Design Process (EDP) principles from Science, Technology, Engineering, and Mathematics (STEM) has led to the development of a new learning model named Innovative Project Design Based Learning (IPDBL) designed to enhance critical thinking and sciencepreneurship skills. The IPDBL learning model guides students through iterative cycles of thinking about problems, brainstorming ideas, designing and scheduling, prototyping, monitoring, testing, and refining, as well as socialization and reflection. Through this process, the IPDBL learning model encourages both critical thinking and the creation of solutions with entrepreneurial and sustainable value. This study examines the development, validation, and effectiveness of the IPDBL learning model in fostering critical thinking skills and sciencepreneurship among Junior High School students [12, 14].

2. Literature Review

2.1. Critical Thinking Skills (CTS)

Critical thinking refers to the ability to think rationally and reflectively with an emphasis on making decisions about what to believe or do [4]. Another perspective defines critical thinking as a directed thought process to solve problems, interpret statements, and resolve problems effectively [3]. Critical thinking skills (CTS) are categorized as higher-order thinking skills and considered essential 21st-century skills [15]. These skills enable students to use information from various sources and experiences to gain a broader perspective and a deeper understanding. According to Ennis, 12 indicators of CTS can be classified into five groups of thinking skills, namely providing elementary clarification, building basic support, interference, making advanced clarification, and strategy and tactics [4]. Meanwhile, according to Facione, indicators of critical thinking skills include interpretation, analysis, evaluation, inferences, explanations, and self-regulation [3].

In science learning, CTS encompasses students' abilities to analyze information, evaluate scientific evidence, interpret data, and justify conclusions based on logical and scientific reasoning [15]. CTS needs to be systematically developed, one way of which is through learning activities that support the critical thinking process. Various studies have shown that science learning can improve students' CTS because the involved indicators can be effectively trained through instructional practices [8, 16, 17].

2.2. Sciencepreneurship

Sciencepreneurship is an ability that connects the mastery of scientific concepts with an entrepreneurial mindset, innovation, and problem-solving based on real-world contexts. This approach emphasizes that scientific knowledge is not only learned as theory but also applied to produce products or solutions with practical, economic, and social value [10, 11]. In the school context, sciencepreneurship becomes increasingly recognized as a strategy to enhance the relevance of science learning while fostering students' creativity, independence, and orientation toward innovation. A recent study has shown that integrating entrepreneurship education into science learning has a positive impact on students' innovative thinking, opportunity recognition, and decision-making skills [13].

However, prior studies related to sciencepreneurship at the junior high school level remain relatively limited. Most research focuses on higher education and vocational education [18]. Research conducted at the school level indicates that science learning integrated with entrepreneurial-oriented projects can increase student motivation, creativity in product development, and understanding of the application of scientific concepts in everyday life [19, 20]. However, several studies remain exploratory and are not yet supported by a comprehensive and validated learning framework. Therefore, developing a structured and innovative learning model that integrates project design, scientific inquiry, and sciencepreneurship principles is crucial to support the holistic development of students' critical thinking skills and entrepreneurial competencies [21, 22].

3. Methodology

3.1. Research Design

This study is an educational development research referring to McKenney's development model [23]. This study was specifically intended to develop, test, and refine educational innovations through iterative cycles conducted in authentic learning settings [24]. The development process in this study consisted of three interconnected stages. The first stage involved a preliminary investigation, including a literature review, needs analysis, and classroom observations, to identify gaps in students' critical thinking skills and sciencepreneurship. The second stage focused on model development, which encompassed the design of the Innovative Project Design-Based Learning (IPDBL) model, the preparation of teaching materials, and expert validation. The final stage comprised implementation and evaluation, during which the IPDBL model was applied in classroom settings, data were systematically collected, and refinements were made based on empirical findings [23].

3.2. Research Setting and Participants

The study was conducted at Junior High School in the Indonesian School of Kuala Lumpur, Malaysia, during the 2024/2025 academic year. Participants were 99 eighth-grade students who were randomly selected from a total of 120 students [25]. The research sample was then divided into four classes: one control class ($n = 30$) receiving instruction using project-based learning (PjBL) and three experimental classes (Class A, $n = 23$; Class B, $n = 23$; Class C, $n = 23$) implementing the IPDBL learning model. Science learning activities were designed with a focus on environmental sustainability and entrepreneurship-related contexts to ensure alignment with the 21st-century skills and sustainable science education.

3.3. Instruments and Data Collection

The data required in this study consisted of the validity of the IPDBL learning model and its teaching materials, students' critical thinking skills, and students' sciencepreneurship. The data were obtained using expert validation, critical thinking skills tests, and sciencepreneurship tests, respectively. Expert validation was employed to assess the content and construct validity of the IPDBL learning model and its teaching materials, including lesson plans, student worksheets, student books, the CTS test, and the sciencepreneurship (SP) test. The CTS test consisted of 10 items with 5 CTS indicators adapted from Ennis's framework, including analyzing arguments, considering observation results, making inductions, evaluating phenomena based on concepts, and deciding on appropriate actions [4]. The SP test consists of 10 item questions with 4 SP indicators, including students' abilities in innovation, problem-solving, creativity, and value creation within STEM contexts [26]. In addition, student response questionnaires were administered to examine perceptions of the model's practicality, clarity, and overall learning experience.

3.4. Data Analysis

3.4.1. Analysis of Validity and Reliability

This study developed the teaching materials, including the IPDBL learning model, lesson plan, student worksheets, student books, critical thinking skills test, and sciencepreneurship test. Before being used for data collection, the teaching materials were validated by three experts in science education.

Validity of teaching materials was measured using the Aiken value, calculated using the following equation [27]:

$$V = \frac{\Sigma s}{n\,(c-1)}$$

Note: V = Validity of item (Aiken value), s =The score given by the validator is subtracted from the lowest score (r – lo), where r = Score given by the validator, c = Highest validity score (in this case = 5), lo = Lowest validity score (in this case = 1), n = Number of validators. The obtained Aiken value is interpreted for validity according to the criteria presented in Table 1.

Table 1.
Interpretation criteria for the Aiken value.

Aiken value	Criteria	Description
0.80-1.00	Very high validity	Can be used without revision
0.60-0.79	High validity	Can be used without revision
0.40-0.59	Moderate validity	Item needs minor revision and re-evaluation, or can be accepted if no better alternative is available.
0.20-0.39	Low validity	The item requires major revision or should be considered for elimination.
0.00-1.19	Very low validity	The item must be eliminated or completely revised.

Source: Rahman et al. [26].

Meanwhile, the reliability of the instruments was assessed based on the interrater agreement obtained from the statistical analysis of the percentage of agreement (PA).

$$PA = \left[1 - \frac{A-B}{A+B}\right] x\ 100\%$$

Note:
A = The frequency of the aspect observed by the observer, giving a high frequency
B = The frequency of the aspect observed by the observer, giving a low frequency

Observer in this study is a validator. The results of the validation of the instruments are reliable if they have a percentage ≥ 75% [16, 26].

3.4.2. Analysis of the Improvement of Students' Critical Thinking Skill and Sainspreneurship
3.4.2.1. Analysis of N-Gain Score

The data obtained were pretest and posttest scores for students' critical thinking skills and sciencepreneurship. The improvement of students' critical thinking skills and sciencepreneurship was conducted by determining the normalized gain score, which was calculated using the following equation [8].

$$g = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}}$$

Note: *Spost* is the post-test score, *Spre* is the pre-test score, and *Smax* is the maximum possible score. The interpretation criteria for the N-gain score are presented in Table 2.

Table 2.
Interpretation of *N*-gain score.

N-gain score	Category	Interpretation
g > 0.70	High	Significant improvement
0.30 < g ≤ 0.70	Moderate	Moderate improvement
g ≤ 0.30	Low	Minimal improvement

Source: Lestari, et al. [8].

3.4.2.2. Inferential Analysis

Inferential statistical analysis was conducted to determine the effectiveness of the IPDBL learning model in improving students' critical thinking skills and sciencepreneurship. A one-way analysis of variance (ANOVA) was used to examine whether there were significant differences in post-test scores for critical thinking skills and sciencepreneurship between the control and the experimental classes (Classes A, B, and C). Before conducting the ANOVA, the post-test scores data were tested for normality and homogeneity. When these assumptions were not met, a nonparametric analysis using the Kruskal–Wallis test was applied [25].

4. Results and Discussion

4.1. Development of IPDBL Learning Model

The new learning model, named Innovative Project Design-Based Learning (IPDBL), was developed to improve junior high school students' critical thinking skills and science entrepreneurship. This model is grounded in various learning theories, including discovery learning, information processing theory, Piaget's theory of cognitive development, and Vygotsky's sociocultural theory. These theories aim to facilitate students in constructing knowledge and developing essential skills. The IPDBL learning model was designed as an innovative form of project-based learning (PjBL) that integrated the principles of the Engineering Design Process (EDP) within STEM education. It consisted of seven phases/syntax: (1) Thinking problem, (2) Brainstorming ideas, (3) Design and Schedule, (4) Prototyping, (5) Monitoring, (6) Testing and refining, and (7) Socialization and reflection (see Figure 1).

Various theoretical and empirical studies, as well as review articles, demonstrate the importance of creativity and collaboration in the IPDBL learning model, with each phase built on a strong theoretical foundation. For example, the Thinking Problem phase is grounded in constructivist theory, which emphasizes the active construction of knowledge through personal and environmental experiences [28] while student interaction in this phase is supported by Vygotsky's theory of social learning [29]. This model aims to develop students' self-confidence, open-mindedness, and critical thinking skills in analyzing problems and proposing solutions, which ultimately integrates STEM. The origins of the hypothetical IPDBL learning model are presented in Figure 1. Meanwhile, the learning activities in each syntax of the IPDBL learning model are presented in Table 3.

Learning activities in the IPDBL learning model were designed by considering the following aspects: (1) empirical evidence and logical theoretical rationales for planning; (2) the learning objectives of the developed model, particularly in addressing the problem of low critical thinking skills and sciencepreneurship among junior high school students; (3) the teaching behaviors and activities required for effective learning; and (4) the learning environment needed to achieve the intended learning objectives. These characteristics were articulated in the IPDBL model book, which consists of the syntax, social system, principles of reaction, support system, instructional impact, and mentoring impact, along with indicators of critical thinking skills and sciencepreneurship that were developed in students at each stage of the syntax [29, 30].

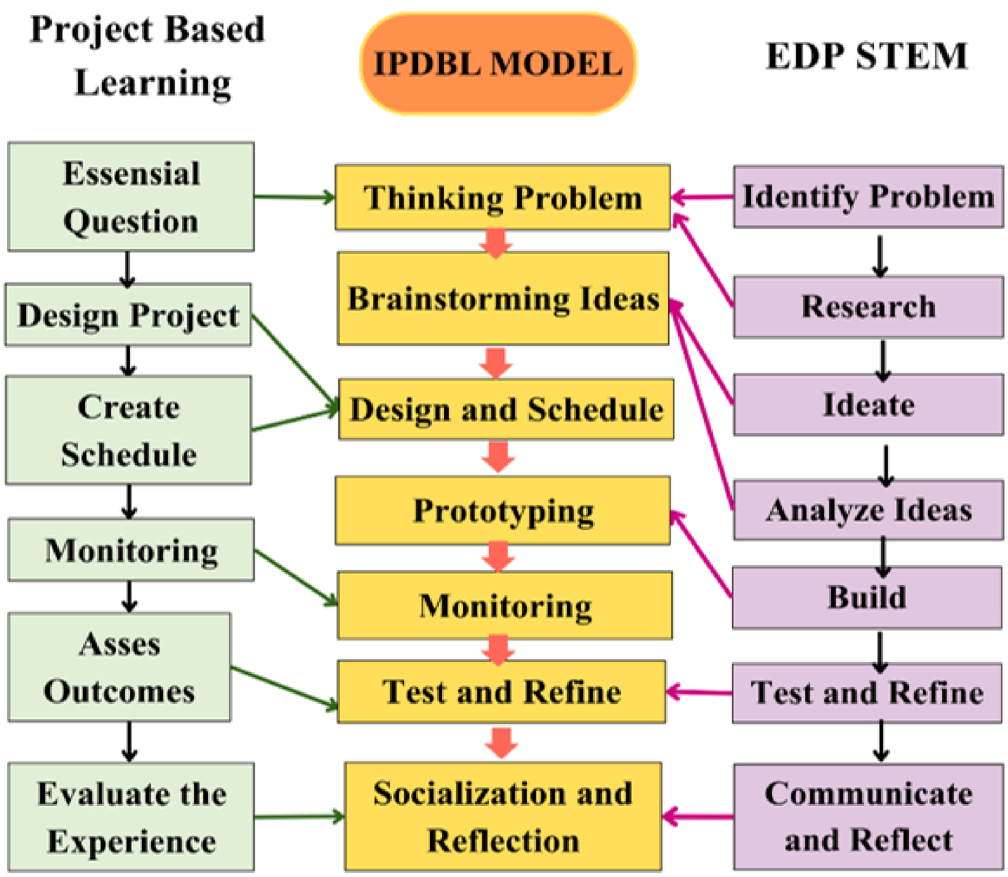

Figure 1.
The origin of the hypothetical IPDBL learning model.

Table 3.
Learning activities in the IPDBL learning model, along with the CTS and sciencepreneurship indicators trained.

No.	Syntax of IPDBL	Learning activities	CTS indicator	Sciencepreneurship indicator
1	Thinking problem	Identify and analyze a real-world problem individually or in groups	Analyzing arguments	Observation, new ideas
2	Brainstorming ideas	Generate multiple solutions, discuss in groups, and present ideas in class	Making inductions, Analyzing arguments	New ideas, creativity
3	Design and schedule	Plan the project workflow, assign roles, and create a schedule	Deciding on appropriate actions	Innovation, value, new ideas
4	Prototyping	Develop project prototype, experiment with ideas	Evaluating phenomena based on concepts, analyzing arguments, and making induction	Innovation, creativity
5	Monitoring	Track project progress, record observations, analyze failures, determine corrective actions, and report to the teacher.	Evaluating phenomena, deciding on appropriate actions	Observation, value
6	Test and refine	Test the prototype, identify errors, and refine solutions	Deciding on appropriate actions	Innovation, value
7	Socialization and reflection	Present results, answer questions from judges and audience, and sell products at the booth	Evaluating phenomena, deciding on appropriate actions	New ideas, value, innovation

4.2. Validity of IPDBL Learning Model

The validation of the IPDBL learning model was conducted with the assistance of three experts in science education. The assessment of the model's validity included content validity and construct validity. Content validity encompasses aspects related to the model's intervention needs, while construct validity refers to the logical and systematic design of the intervention model. The validation results of the hypothetical IPDBL learning model are presented in Table 4.

Table 4.
Validation results of the hypothetical IPDBL learning model.

Type of Validity	Component / Statement	Validation Result	Validity category	Reliability (%)	Reliability category
Content Validity	Clarity of model background	0.93	Very high	95.24	Reliable
	Clarity of up-to-date knowledge (State of the art)	0.94	Very high	95.24	Reliable
	Appropriateness of model planning and implementation	0.94	Very high	94.29	Reliable
Average scores		0.94	Very high	94.92	Reliable
Construct Validity	Indicators of student skills align with model constructs	0.94	Very high	94.29	Reliable
	Relationship between indicators and model objectives	0.94	Very high	95.24	Reliable
Average scores		0.94	Very high	94.77	Reliable
Average scores		0.94	Very high	94.89	Reliable

Table 4 showed that the content validity and construct validity of the IPDBL learning model obtained Aiken values of 0.94, respectively. Because it was greater than 0.80, the validity of the IPDBL learning model was categorized as very high [27]. Moreover, the reliability of the validator's assessment results for the IPDBL learning model was greater than 75%, categorized as reliable [16, 26]. Thus, the IPDBL learning model was valid and reliable and therefore met the requirements for implementation in science learning.

4.3. Validation Results of Teaching Materials Based on IPDBL Learning Model

The teaching materials developed based on the IPDBL learning model, whose validity was tested, consisted of lesson plans, student worksheets, student books, the CTS test, and the sciencepreneurship test. The validation assessment was conducted by three experts in science education. The results of the validation assessment are presented in Table 5.

Table 5.
The results of the validation of teaching materials based on the IPDBL learning model.

Teaching materials	Type of validity	Aiken value	Validity category	Reliability (%)	Reliability category
Lesson plan	Content validity	0.97	Very high	97.81	Reliable
	Construct validity	0.98	Very high	98.10	Reliable
Average scores		0.98	Very high	97.96	Reliable
Student worksheet	Content validity	0.98	Very high	98.41	Reliable
	Construct validity	0.95	Very high	95.92	Reliable
Average scores		0.97	Very high	97.17	Reliable
Student book	Content validity	0.99	Very high	99.32	Reliable
	Construct validity	0.95	Very high	96.19	Reliable
Average scores		0.97	Very high	97.76	Reliable
CTS test	Content validity	0.98	Very high	98.10	Reliable
	Construct validity	0.99	Very high	99.05	Reliable
Average scores		0.99	Very high	98.58	Reliable
Sciencepreneurship test	Content validity	1.00	Very high	100.00	Reliable
	Construct validity	1.00	Very high	100.00	Reliable
Average scores		1.00	Very high	100.00	Reliable
Average scores		0.98	Very high	98.29	Reliable

Based on the validity measurement results (Table 4), the lesson plan, student worksheet, student book, CTS test, and sciencepreneurship test obtained Aiken values of 0.98, 0.97, 0.97, 0.99, and 1.00, respectively. Therefore, the validity of the five teaching materials was categorized as very high, as all values exceeded 0.80 [27]. Meanwhile, based on the validators' assessment results, all teaching materials showed reliability values greater than 75%, indicating that they were categorized as reliable [16, 26]. Thus, the teaching materials developed based on the IPDBL learning model were valid and reliable and met the requirements for implementation in science learning

4.4. Analysis of Students'critical Thinking Skills

4.4.1. N-Gain Score Analysis of Students'Critical Thinking Skills

The IPDBL learning model was implemented on the topic of food additives for 8th-grade students at Kuala Lumpur Indonesian School, Malaysia. A total of 99 students participated, including a control class (n=30) and experimental classes A (n=23), B (n=23), and C (n=23). Students' critical thinking skills were measured using the CTS test before (pre-test) and after learning with the IPDBL model (post-test). The results of the CTS test are presented in Table 6 and Figure 2.

Table 6.
Results of pre-test, post-test, and *N*-gain CTS.

No.	Sample	Average score of the pre-test	Average score of the post-test	*N*-gain	Category
1	Control class	26.47	49.80	0.318	Moderate
2	Experimental class A	27.57	75.04	0.660	Moderate
3	Experimental class B	25.65	77.04	0.687	Moderate
4	Experimental class C	29.48	80.87	0.729	High

Table 6 showed that the average post-test scores of the experimental classes A (75.04), B (77.04), and C (80.87) were with an overall average post-test score of 77.65 (high category) [27]. This score was higher than that of the control class (49.80) (very low category) [27]. This finding is further supported by the *N*-gain scores of the experimental classes A (0.660), B (0.687), and C (0.729) with an overall average *N*-gain score of 0.692 (moderate category) [8]. These *N*-gain scores were also higher than those of the control class (0.318). Therefore, it can be concluded that the IPDBL learning model is highly effective in improving junior high school students' critical thinking skills in learning the topic of food additives. Table 7 portrays the improvement in students' critical thinking skills supported by the increases in each indicator.

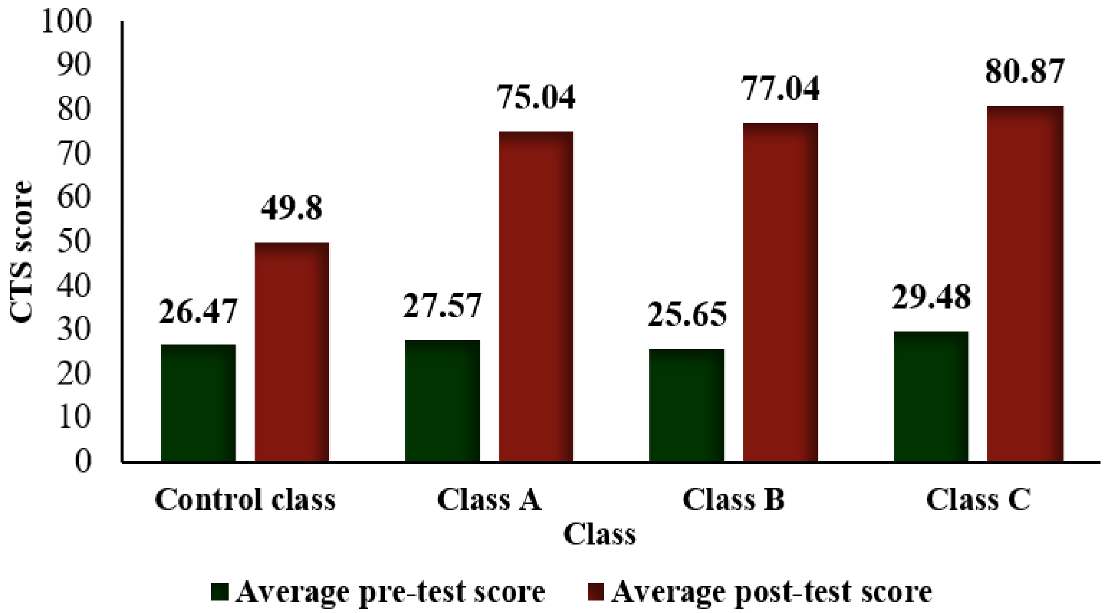

Figure 2.
Average pre-test and post-test scores of CTS.

Table 7.
The average post-test scores for each CTS indicator of the control class and experimental class (A, B, and C).

No.	CTS indicator	Average post-test scores of the control class	Average post-test scores of the experimental class			
			Class A	Class B	Class C	Average score
1	Analyzing arguments	62.0	66.0	83.5	82.6	77.37
2	Considering observation results	43.3	72.0	71.7	77.4	73.70
3	Making inductions	45.7	82.0	77.0	81.7	80.23
4	Evaluating phenomena based on concepts	38.3	70.0	80.0	81.7	77.23
5	Deciding on appropriate actions	59.7	78.0	73.0	80.9	77.30

Based on the analysis of post-test scores for each CTS indicator (Table 7 and Figure 3), the average scores across the five CTS indicators in the experimental class were higher than those in the control class. These results provide evidence that the IPDBL learning model is highly effective in improving students' CTS. In the control class, the analyzing arguments indicator (indicator 1) showed the highest average score (62.0), whereas indicator 4 (Evaluating phenomena based on concepts) showed the lowest average score (38.3). In the experimental class, the making inductions indicator (indicator 3) showed the highest average score (80.23), whereas indicator 2 (Considering observation results) showed the lowest average score (73.70).

4.4.2. Inferential analysis of students' critical thinking skills.

The post-test scores of students' critical thinking skills in the control and experimental classes (A, B, and C) were analyzed to determine whether there were significant differences between the CTS of students in the control class and those in the experimental classes after implementing the IPDBL learning model. Before conducting the mean difference test, the four sets of post-test data were examined for normality and homogeneity using the Shapiro–Wilk test ($n < 50$) and Levene's test, respectively, with the assistance of the SPSS program [31]. The results of the normality test and the homogeneity test are presented in Table 8.

Table 8.
Results of the normality test and homogeneity test for students' critical thinking skills.

Statistical tests	Class	Sig. (*p*-value)	Conclusion
Normality test (Shapiro-Wilk test)	Control class	0.293	Sig > 0.050 (normal)
	Experimental class A	0.404	Sig > 0.050 (normal)
	Experimental class B	0.009	Sig < 0.050 (not normal)
	Experimental class C	0.003	Sig < 0.050 (not normal)
Homogeneity Test (Levene's test)	Control class	0.906	Sig > 0.050 (homogen)
	Experimental class A	0.962	Sig > 0.050 (homogen)
	Experimental class B	0.962	Sig > 0.050 (homogen)
	Experimental class C	0.940	Sig > 0.050 (homogen)

Table 8 showed that, based on the normality test, the CTS post-test score data for the control class and experimental class A are normally distributed, as the obtained *p*-values were greater than 0.05. In contrast, the CTS post-test score data for experimental classes B and C were not normally distributed, as the p-values were less than 0.05 [31]. Therefore, the mean difference analysis of the four sets of CTS post-test data was conducted using nonparametric statistical methods, namely the Kruskal–Wallis test, followed by the Mann–Whitney *U* test [31]. The results of these analyses are presented in Tables 9 and 10.

Table 9.
Results of the Kruskal-Wallis test for students' critical thinking skills.

Sample	*N*	Mean rank	df	Chi-square (*H*)	Sig. (*p*-value)	Significance
Control class	30	25.78	3	40.835	0.000	Significantly different
Experimental class A	23	44.96				
Experimental class B	23	68.48				
Experimental class C	23	68.15				

Table 10.
Results of the Mann-Whitney *U* test for students' critical thinking skills.

Comparation	*U* Statistic	Sig. (*p*-value)	Significance
Control class vs experimental class A	161.000	0.001	Significantly different
Control class vs experimental class B	73.500	0.000	Significantly different
Control class vs experimental class C	74.000	0.000	Significantly different

Based on the Kruskal–Wallis test in Table 9, a *p*-value of 0.000 was obtained. Since this value was less than 0.05, the four sets of CTS post-test mean scores were significantly different. The results of post hoc analysis using the Mann–Whitney *U* test further confirmed that the average critical thinking scores of students in the experimental classes (A, B, and C) were significantly different from those of the control class [31]. These findings support the conclusion that the implementation of the IPDBL learning model on the topic of food additives is effective in improving junior high school students' critical thinking skills.

The results of the *N*-gain score analysis and the Kruskal–Wallis test showed that the developed IPDBL learning model had a significant effect on improving students' critical thinking skills. The IPDBL syntax, consisting of thinking problems, brainstorming ideas, design and schedule, prototyping, monitoring, testing and refining, and socialization and reflection, effectively supported the development of the targeted critical thinking indicators. These seven stages systematically encourage analytical, critical, evaluative, and reflective thinking. The project assignment of creating healthy food using natural additives stimulated students' cognitive engagement in the initial phase, thinking problems, and *brainstorming ideas* [4, 32]. The design, schedule, and prototyping phases promoted analytical

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reasoning, critical thinking, and evidence-based decision making [15, 33]. The monitoring, testing, and refining phases enhanced metacognitive regulation [17, 34]. The final phase, socialization and reflection, further strengthens evaluative judgment by linking theoretical understanding with practical application [35]. Overall, these findings suggest that the IPDBL learning model provides an effective pedagogical framework for enhancing students' analytical reasoning, problem-solving, and reflective thinking, which are key components of students' critical thinking development.

4.5. Analysis of Students' Sciencepreneurship

4.5.1. N-Gain Score Analysis of Students' Sciencepreneurship

In this study, the implementation of the IPDBL learning model was also examined for its effect on improving students' sciencepreneurship. It was measured using a sciencepreneurship test conducted both before (pre-test) and after (post-test) the learning process using the IPDBL learning model. The results of the sciencepreneurship test are presented in Table 11 and Figure 3.

Table 11.
Results of pre-test, post-test, and *N*-gain sciencepreneurship.

No.	Sample	Average score of the pre-test	Average score of the post-test	*N*-gain	Category
1	Control class	40.53	56.13	0.262	Low
2	Experimental class A	22.26	75.48	0.685	Moderate
3	Experimental class B	19.30	82.61	0.785	High
4	Experimental class C	23.13	85.91	0.817	High

Based on Table 11, the average post-test scores of the experimental classes A (75.48), B (82,61), and C (85.91) with an overall average post-test score of 81.33 (high category) [27]. These values were higher than those of the control class (56.13) (low category) [27]. This finding is further supported by the *N*-gain scores of the experimental classes A (0.685), B (0.785), and C (0.817) with an overall average *N*-gain score of 0.762 (high category) [8]. This *N*-gain score was also higher than that of the control class (0.262) (low category) [8]. Therefore, it can be concluded that the implementation of the IPDBL learning model at junior high school science learning on the topic of food additives had a very positive effect on improving students' sciencepreneurship.

Table 12.
The average post-test scores for each sciencepreneurship indicator of the control class and experimental class (A, B, and C).

No.	Sciencepreneurship indicator	Post-test of the control class	Post-test of experimental class			
			Class A	Class B	Class C	Average score
1	Observation	61.90	74.20	88.70	89.60	84.17
2	New ideas	63.20	91.70	94.80	95.70	94.07
3	Innovation	45.80	75.80	83.50	82.60	80.63
4	Creativity	53.50	68.30	72.20	86.10	75.53
5	Value	56.80	64.20	73.90	83.50	73.87

Table 12 and Figure 5 showed that the average scores across the five sciencepreneurship indicators in the experimental class were higher than those in the control class. These results prove that the IPDBL learning model is highly effective in improving students' sciencepreneurship. In the control class, the new ideas indicator (indicator 2) showed the highest average score (63.20), whereas indicator 4 (creativity) showed the lowest average score (53.50). In the experimental class, the making inductions indicator (indicator 3) showed the highest average score, which was also owned by the new ideas indicator (94.07), whereas the final indicator (value) showed the lowest average score (73.87).

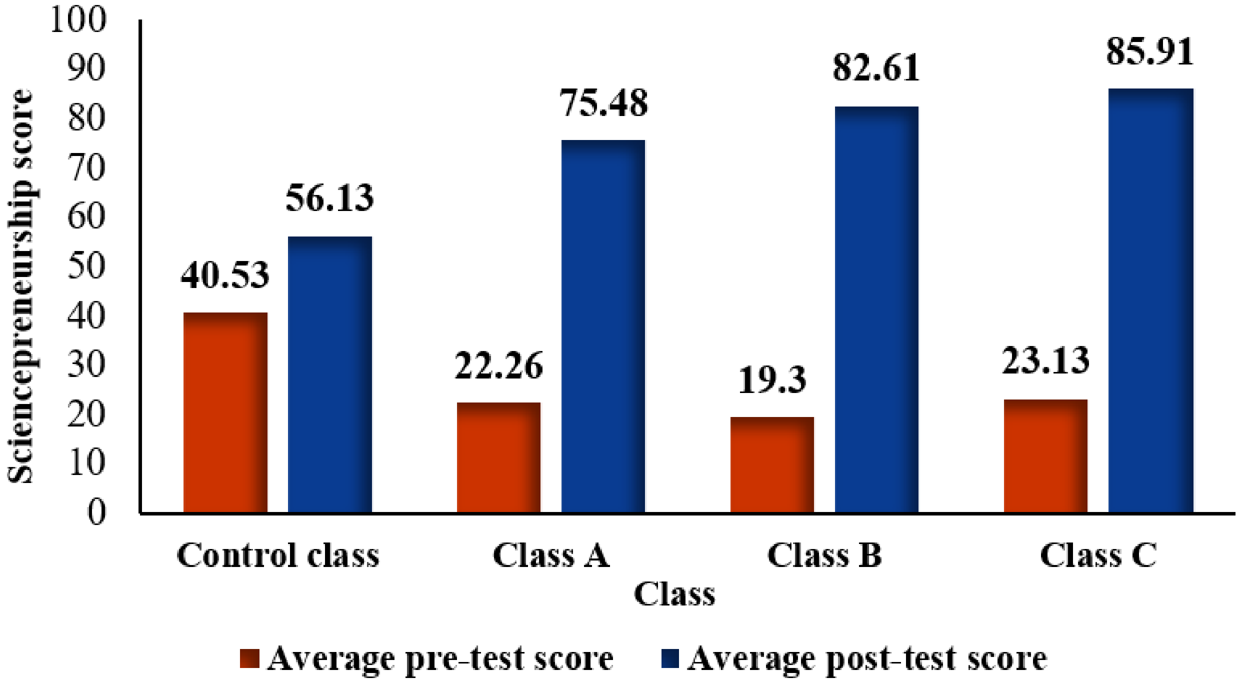

Figure 3.
Average pre-test and post-test scores of sciencepreneurship.

4.5.2. Inferential Analysis of Students' Sciencepreneurship

In this study, the post-test scores of students' sciencepreneurship for the control and experimental classes (A, B, and C) were analyzed using inferential statistics to determine whether there were significant differences in students' sciencepreneurship between the control and experimental classes after the implementation of the IPDBL learning model. Before conducting the mean difference analysis, the four sets of post-test data were first tested for normality and homogeneity. The normality and homogeneity tests were performed using the Shapiro–Wilk test ($n < 50$) and Levene's test, respectively, with the assistance of the SPSS program [31]. Table 13 shows the results of the normality test and homogeneity test of the post-test scores of students' sciencepreneurship.

Table 13.
Results of the normality test and homogeneity test for students' sciencepreneurship.

Statistical tests	Class	Sig. (p-value)	Conclusion
Normality test (Shapiro-Wilk test)	Control class	0.293	Sig > 0.050 (normal)
	Experimental class A	0.033	Sig < 0.050 (not normal)
	Experimental class B	0.001	Sig < 0.050 (not normal)
	Experimental class C	0.000	Sig < 0.050 (not normal)
Homogeneity Test (Levene's test)	Control class	0.412	Sig > 0.050 (homogen)
	Experimental class A	0.721	Sig > 0.050 (homogen)
	Experimental class B	0.721	Sig > 0.050 (homogen)
	Experimental class C	0.638	Sig > 0.050 (homogen)

Based on the normality test in Table 13, the sciencepreneurship post-test score data for the control class were normally distributed, as the obtained p-values were greater than 0.05. In contrast, the sciencepreneurship post-test score data for all experimental classes were not normally distributed, as the p-values were less than 0.05. Therefore, the mean difference analysis of the four sets of sciencepreneurship post-test data was conducted using nonparametric statistical methods, namely the

Kruskal–Wallis test, followed by the Mann–Whitney *U* test [31]. The results of these analyses are presented in Tables 14 and 15.

Table 14.
Results of the Kruskal-Wallis test for students' sciencepreneurship.

Sample	*N*	Mean rank	df	Chi-square (*H*)	Sig. (*p*-value)	Significance
Control class	30	25.78	3	48.380	0.000	Significantly different
Experimental class A	23	44.96				
Experimental class B	23	68.48				
Experimental class C	23	68.15				

Table 15.
Results of the Mann-Whitney *U* test for students' sciencepreneurship.

Comparation	*U* Statistic	Sig. (*p*-value)	Significance
Control class vs experimental class A	103.500	0.000	Significantly different
Control class vs experimental class B	45.500	0.000	Significantly different
Control class vs experimental class C	53.000	0.000	Significantly different

Table 14 indicated that, based on the Kruskal–Wallis test, a p-value of 0.000 was less than 0.05, so the four sets of sciencepreneurship post-test mean scores were significantly different. The average sciencepreneurship post-test scores of students in the experimental classes (A, B, and C) were significantly different from those of the control class, based on the post hoc analysis using the Mann–Whitney U test (see Table 15) [31]. These findings support the conclusion that implementing the IPDBL learning model on the topic of food additives effectively improves Junior High School students' sciencepreneurship.

Based on the results of the *N*-gain score analysis and the Kruskal–Wallis test, the developed IPDBL learning model also demonstrated a significant effect on improving students' sciencepreneurship. The seven stages of the IPDBL learning model were shown to effectively develop the five indicators of sciencepreneurship: observation, new ideas, innovation, creativity, and value. The project assignment of producing healthy food using natural additives stimulated students' cognitive engagement in developing all five indicators of sciencepreneurship. Students were trained to integrate scientific concepts related to food additives with practical innovations that have the potential to generate economic value. These experiences fostered an initial awareness of entrepreneurship and enhanced students' ability to identify opportunities for science-based product development [10, 11, 19].

The IPDBL learning model facilitated active student engagement throughout the learning process through project-based activities, enabling students to develop initiative, creativity, and responsibility, which are essential components of sciencepreneurship [20, 35, 36]. Observer also stated that key aspects of sciencepreneurship, such as the generation of innovative ideas and the final socialization and reflection phase (e.g., preparing for an innovative product exhibition), were implemented consistently and effectively. Furthermore, students also provided very positive feedback on the planning and design of innovative products related to healthy food free from chemical additives and offered forward-looking suggestions, demonstrating the successful transfer of project experiences into a proactive, creative, and economically conscious mindset. Overall, the integration of entrepreneurship and sustainability within the IPDBL learning model strengthens students' ability to develop science-based, innovative, and context-responsive solutions. These findings support previous research emphasizing the role of STEM-based project learning in fostering sciencepreneurship and align with the goals of Education for Sustainable Development (ESD) [37, 38].

5. Conclusions

This study successfully developed, validated, and tested a new IPDBL learning model to improve critical thinking skills (CTS) and sciencepreneurship among junior high school students on the topic of food additives. The IPDBL learning model consists of seven stages: thinking problems, brainstorming ideas, design and scheduling, prototyping, monitoring, testing and refining, and socialization and reflection. The results showed that the IPDBL learning model and its supporting teaching materials, including lesson plans, student books, student worksheets, CTS tests, and sciencepreneurship tests, had very high validity, with Aiken's V of 0.94, 0.98, 0.97, 0.97, 0.99, and 1.00, respectively. Furthermore, the IPDBL learning model and its teaching materials were also reliable, with a percentage of agreement (PA) exceeding 75%. The IPDBL learning model was highly effective in improving CTS and sciencepreneurship among junior high school students, as the N-gain scores of the experimental class fell into the medium to high categories and were higher than those of the control class (0.692/0.762 vs 0.318/0.262). Moreover, the Kruskal–Wallis test, followed by the Mann–Whitney U test, showed that the average post-test scores of the experimental class were significantly different from those of the control class. Therefore, the IPDBL model can be used as an innovative learning approach in science education to support the Sustainable Development Goals (SDGs) by improving the quality of education.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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