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The Effectiveness of Guided Inquiry-Based Worksheet on Synthetic and Natural Food Colorant Thin Layer Chromatography Practicum on Developing Scientific Explanation Skills

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Abstract: Scientific explanation is an essential skill in chemistry learning because it connects scientific principles and objective evidence. This study aims to describe the application of guided inquiry-based learning in thin-layer chromatography experiments of synthetic and natural food coloring to develop students' scientific explanations in learning applications. This study used a pre-experimental method with a post-test only one-shot case study design. In the implementation of learning, the implementation rate reached 87%. The average scores for worksheets and scientific explanation tests were 78 and 79, respectively. This indicates that the application of guided inquiry-based worksheets through TLC experiments is practical in developing students' scientific explanation skills. This experiment can be adopted in broader chemistry learning contexts by integrating guided inquiry with thin-layer chromatography using real food colorants, thereby fostering scientific thinking and providing students with hands-on experience that emphasizes the relevance of chemistry in everyday life.

Keywords: Food Coloring; Guided Inquiry; Scientific Explanation; Student Worksheet; Thin Layer Chromatography.

Introduction

Food coloring is one of the compounds classified as food additives [1]. As the name suggests, this compound is used to enhance the appeal and visual appearance of the final food product [2]. Based on their source, food colorings are divided into two types: synthetic and natural. Synthetic food colorants often use more than one primary color to achieve a specific color [2]. Meanwhile, natural colorants are food additives obtained from natural sources such as plants, animals, minerals, and microorganisms [3]. One fruit with potential as a food colorant is the *Syzygium oleana*. The *Syzygium oleana* fruit belongs to the *Myrtaceae* family. The purple-colored *Syzygium oleana* fruit is a potential source of natural food coloring. Although both the leaves and fruits contain anthocyanins, the fruit is a stronger source for coloring purposes [4].

Their economic value may drive the use of synthetic food colorants compared to natural colorants. However, despite being tested by regulatory bodies such as the FDA and EFSA, the safety of synthetic colorants remains a matter of controversy [3]. In addition to lacking nutritional and health benefits, prolonged use can lead to the accumulation of these components in the body. This, of course, has the potential to cause long-term health issues. Therefore, a method is needed to identify and separate these dyes in food. One separation method is thin-layer chromatography (TLC) [5].

TLC can be applied in various fields, from organic chemistry, phytochemistry, and biotechnology, to analyzing food content, such as synthetic and natural dyes [1], [6], [7]. The separation of components in TLC is based on the difference in affinity between the stationary phase and the mobile phase. This interaction causes different components to move at different speeds. Although this material is easy to understand, students need to conduct experiments to gain a deeper understanding of the chemical principles behind the procedure [8].

Practising TLC allows students to observe and explain how the intermolecular forces (IMF) between the sample and the stationary phase (e.g., silica or alumina) and the mobile phase determine the movement of compounds and their Rf values [9]. Inquiry-based learning is highly suitable for chemistry education due to its experimental nature and applicability in worksheets [11], [12]. Students can gain experience in designing and conducting experiments, making observations, collecting and analyzing data, and evaluating hypotheses [10]. Significantly, inquiry-based learning can develop students' skills by encouraging active engagement. A scientific explanation is an essential skill for students to master in chemistry, especially for university students [13]. This skill involves making claims that explain a phenomenon by connecting scientific principles with empirical evidence and justifying those claims using appropriate ideas and evidence [11], [12]. However, despite the importance of this skill, many studies show that students still struggle to develop scientific explanations [13]. The results of the Programme for International Student Assessment (PISA) in 2015 indicate that students' scientific explanation skills in Indonesia are still relatively low [14]. Learning progress that does not keep pace with the times and does not guide students in developing their potential leaves students unaccustomed to

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applying their knowledge to explain phenomena scientifically [14], [15].

The research by Sulistina et al. [15] indicates that classes that received guided inquiry-based learning resulted in 32% of students achieving a level 4 scientific explanation quality. The research by Rojikin et al. [16] reveals that the electronic module developed for digestive system material can serve as a tool to facilitate learning and develop scientific explanation skills. Meanwhile, Sattar [17] conducted a series of experiments. The first experiment involved preparing paint pigments, namely, historical lake dyes. These dyes are made from natural pigments derived from plants and insects, typically using madder and cochineal or scale insects. The prepared dyes were then tested using TLC to identify the main dyes, namely alizarin and purpurin, extracted from wool dyed with madder. This experiment aimed to provide students with hands-on experience in identifying components, calculating Rf values, and explaining why sample components are farther apart than others.

While prior studies have explored the use of thin layer chromatography and guided inquiry-based learning as individual pedagogy strategies to enhance students' scientific explanation skills, they have not investigated the potential of integrating both approaches in a cohesive manner. By combining the use of TLC worksheets with an inquiry-based framework, this study aims to bridge the gap between theoretical understanding and practical application. Not only can students engage in the scientific process of separating food dye components, but they can also develop scientific explanation skills as they interpret their findings with this integration**.** In addition, there has been no research separating red fruit extracts using TLC methods. Therefore, it is necessary to apply student worksheets in TLC to separate food dye components, both synthetic and natural, so that they can serve as an effective tool in developing students' scientific explanation skills.

Research Methods

This study used a pre-experimental method with a one-shot case study post-test only design, with 30 sixth-semester students in the Chemistry Education program at UIN Sunan Gunung Djati Bandung as subjects. The design used is presented in Table 1.

Table 1. Research Design

X	O
Treatment of interdependent variables	Observation of dependent variables

The research was conducted by providing treatment, specifically guided inquiry-based student worksheets on synthetic and natural food coloring thin-layer chromatography in groups to develop scientific explanation skills. At the end of the learning process, students were given scientific explanation questions to determine the development of their scientific explanation skills. In this research, the absence of a pre-test was a deliberate choice aimed at ensuring a clearer assessment of the impact of the guided inquiry-based student worksheets on scientific explanation skills.

By conducting a post-test only, the study will focus on evaluating the direct outcome of the intervention, free from any potential biases that could arise from the pre-test familiarity. This approach allowed more authentic measurement of learning gains, highlighting the immediate effects of inquiry-based learning experience without the confounding variables introduced by prior testing. Moreover, the interpretation of learning gains from the post-test alone provides insight into the effectiveness of the worksheets in enhancing students' skills. However, it's important to recognize that while this method captures the outcomes of the intervention, it does not account for students' prior knowledge or skills, which could influence their performance. Therefore, the findings should be viewed within this context, acknowledging that the baseline understanding of students may vary widely.

Several methods were used to obtain accurate data during the research. Qualitative data were obtained from observation sheets of student activities, while quantitative data were obtained from the assessment of worksheets and scientific explanation questions. The research instruments, including the learning description, student activity observation sheets, student worksheets, and scientific explanation questions, were first validated by three Chemistry Education lecturers at UIN Sunan Gunung Djati Bandung. The validation results indicated that the instruments were valid and could be used. To calculate the final results of each instrument used, equation (1) can be applied.

$$X = \frac{\Sigma n}{N} \times 100\% \qquad (1)$$

X = Final score
Σn = Total instrument score
N = Total score [18]

The average score on the instrument can be represented in Table 2.

Table 2. Data Categorization

Average Score	Category
80-100	Very Good
66-79	Good
56-65	Fair
40-55	Poor
30-39	Fail

[18]

Final results with a score range of 80–100 are classified as “very good,” reflecting a very high level of achievement. Scores between 66 and 79 are classified as “Good,” indicating a solid mastery of the material. The range of 56–65 is interpreted as “Fair,” suggesting that further understanding is still needed. Meanwhile, scores of 40–55 fall into the ‘Poor’ category, and scores of 30–39 are categorized as “Fail,” meaning they have not met the minimum standards set. To ensure inter-rater reliability and observation consistency, given both the quantitative and qualitative nature of the data collected, clear rubrics and standardized criteria were established to guide their evaluations, enabling them to maintain consistency in scoring. This approach helped to mitigate subjectivity and ensured that the conclusions drawn from the data were robust and dependable.

Results and Discussion

Implementation of the Thin Layer Chromatography Practicum for Synthetic and Natural Food Colorings

The guided inquiry-based learning process, utilizing synthetic and natural food coloring thin-layer chromatography, was conducted in groups that consisted of 7-8 students. Each group was given a worksheet designed to develop scientific explanations. The implementation of this learning was observed by three observers using a student activity observation sheet. The results of the TLC practicum for the synthetic and natural food coloring activity are presented in Table 3.

Table 3. Student Activity Score

No	Guided Inquiry Learning Stages	Average	Category
1	Problem Formulation	82	Very Good
2	Hypothesis Development	90	Very Good
3	Experiment Design	81	Very Good
4	Experiment Implementation	95	Very Good
5	Data Analysis	82	Very Good
6	Conclusion	90	Very Good
Average		87	Very Good

Based on Table 3, the implementation of guided inquiry learning in the thin-layer chromatography practicum of synthetic and natural food coloring has been carried out with an outstanding category. This can be seen from the average score for the implementation of learning, which is 87 [19]. In addition to implementing the guided inquiry learning model, students' ability to complete the worksheet was also assessed. The worksheets were designed based on the guided inquiry stages and included three indicators of scientific explanation skills: claim, evidence, and reasoning. The summary of students' performance in completing the worksheets is presented in Table 4.

Table 4. Student Worksheet Score

No	Guided Inquiry Learning Stages	Average	Category
1	Problem Formulation	70	Good
2	Hypothesis Development	90	Very Good
3	Experiment Design	79	Good
4	Experiment Implementation	75	Good
5	Data Analysis	77	Good
6	Conclusion	80	Very Good
Average		78	Good

The first phase of the guided inquiry worksheet involves formulating the problem. Students are asked to observe the discourse on synthetic and natural food coloring, as well as the application of TLC for compound separation. Additionally, students are asked to identify the main ideas and write two problem statements based on the discourse presented. Referring to Table 4, students were able to formulate problems well with an average score of 70. The second phase is formulating hypotheses. At this stage, students are asked to write hypotheses based on the questions they made in the previous stage. Students are also asked to express their opinions on the separation of synthetic and natural food coloring using TLC. Based on these results, students achieved an average score of 90, which can be categorized as very good.

The first two phases of this guided inquiry learning directly demonstrate the first aspect of scientific explanation, which is analyzing the phenomena presented as claims. A claim is an answer or conclusion to a scientific question or problem presented [20]. The process of analyzing a phenomenon or a discourse requires the students to identify what needs to be explained [21]. This initial act lays the groundwork for forming a claim, which is essentially the answer to the scientific question posed by the problem. By engaging with the problem, the students begin to articulate their initial thought [22]. Hypothesis, on the other hand, is a preliminary claim or proposed explanation for a phenomenon. This phase directly involves students in stating their initial understanding or prediction about the how or why of the phenomenon [11]. It forces them to propose a testable statement, which is a fundamental characteristic of a claim in scientific explanation [22]. Based on the scores obtained, it was found that students could formulate claims based on problem formulation, hypotheses, and express their opinions on the topic being discussed.

The third phase is designing the experiment. At this stage, students were asked to sequence the series of experiments to be conducted. The average score obtained was 79. This score indicates that students can design experiments well, starting from formulating the objectives of the experiment to separate synthetic and natural food coloring components by TLC, determining the principles of the TLC experiment, the tools and materials to be used, to designing the experimental procedure in a flowchart based on the steps presented in the worksheet. Not only does this phase develop the ability to conceptualize causal explanations as claims, but it is also aimed at developing students' ability to analyze data, scientific facts, and principles of the discipline to improve causal explanations as evidence [12].

The purpose of the experiment stated in the worksheet is to test the validity of the hypothesis created in the previous phase. By defining the purpose, students are clarifying what specific causal relationship they need to investigate. This forces them to concretize their abstract causal idea into a testable objective [23]. It also leads them to think about the underlying mechanism of a phenomenon rather than just its observable features [15]. Designing the experiment requires students to consider what specific data will serve as evidence to support or refute their causal claims. The act of listing specific equipment and detailing procedures also requires students to consider how to obtain accurate and complete data. A well-designed procedure, especially if presented in a flowchart, can guide students on how to perform the experiment and what to observe effectively. It can also inherently scaffold the production of scientific explanation. The structured approach helps students to present their findings and create a pathway to corroborate or refute their hypothesis based on empirical evidence [11].

The fourth phase involves experimenting as previously designed. In this phase, students conduct an experiment to separate food coloring using TLC. The experiment begins by preparing the eluent for each sample, setting up the TLC plate, applying the sample, and marking the resulting spots. The students obtained a score of 90. This indicates that the students were able to carry out the previously designed experiment in an orderly manner. Along with this stage, students can collect evidence and be meticulous in observing and recording the results of the practical work that has been carried out [24]. In the Claim, Evidence, and Reasoning (CER) framework, evidence is the data that obtained from an experiment, such as observations, measurements, or calculations that could support the claim [25]. In this experiment, the data are specifically spot color and the distance on the TLC plate. The process for students when conducting a TLC experiment is shown in Figure 1.

Figure 1. Students Doing TLC Experiment

The fifth phase is analyzing the data. In this phase, three questions are provided. The first question asks students to explore the experimental data by determining the Rf value and estimating the polarity of each eluent used. Generally, students can accurately assess the polarity and calculate the Rf value of each solvent mixture. In the second question, students are asked to explain the effect of differences in solvent composition on the Rf value of each chromatography result. Finally, students were asked to determine the number of components and the optimal eluent composition for each sample based on the distance of the spots produced. In this question, students were able to answer accurately. Students could answer that each sample consisted of two components based on the spots obtained. Students also selected the most optimal eluent variation in separating each sample based on the spot distance. For synthetic food coloring, students answered that the eluent was ethanol, n-butanol, and water in a volume ratio of 3:7:1. For the natural sample, which was *Syzygium oleana* extract, the most efficient solvent was an eluent of n-butanol, acetic acid, and water in a volume ratio of 5:4:1.

This phase not only represents the evidence aspect of scientific explanation but also the reasoning aspect. The raw data from experiments, such as spot color and distance, are calculated into Rf value and constitute evidence that supports the claim. The ability to collect, discuss, and interpret this data prepares students to construct meaningful explanations supported by empirical findings [25]. Beyond merely presenting facts, this phase requires students to interpret, connect, and critically evaluate their observations, and any other experimental result, embodying the reasoning aspect of scientific explanation [17]. During this data analysis, students must consciously link the collected evidence to their initial claim or hypothesis, explaining why certain data support or even refute a particular claim [15]. The average score obtained by the four groups was 75. This score indicates that the students can analyze data effectively, discuss data as evidence, and apply their knowledge of causal-mechanistic relationships regarding a phenomenon to support their reasoning.

The final phase involves summarizing the data. This phase represents the reasoning aspect of scientific explanation skills. This phase is crucial because it compels students to move beyond stating observations and instead to interpret, connect, and logically justify their findings based on scientific principles. By emphasizing how and why phenomena occur, students learn to construct causal-mechanistic explanations, which provide a detailed account of the underlying processes. This moves their explanations beyond mere descriptions and into the realm of proper scientific understanding [26]. Students obtained an average score of 80. This score indicates that students are able to conclude the advantages and disadvantages of using TLC in separating sample components and connecting hypotheses with observation results and relevant theoretical sources. After concluding, students were asked to present the worksheets they had created in front of the class. This was intended to facilitate students in explaining and discussing their findings, which could help them clarify initial ideas or claims directly related to the material being studied.

Overall, the average score for the worksheets was 78. This score indicates that students were able to answer the worksheets well. It also shows strong performance in activities that support the development of scientific explanation. Guided inquiry-based learning is student-centered learning that emphasizes active participation, problem solving, and critical thinking. All of these aspects are vital for developing scientific explanation skills [15].

In this experiment, synthetic purple food coloring was used. The synthetic purple food coloring consists of carmoisine and brilliant blue FCF. Carmoisine (CI 14720), also known as azorubine, is a synthetic azo red dye [7]. The structure of the carmoisine compound is shown in Figure 2, while the structure of the brilliant blue FCF compound is shown in Figure 3.

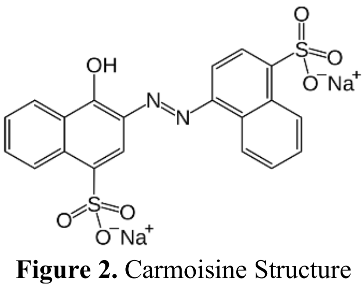

Figure 2. Carmoisine Structure

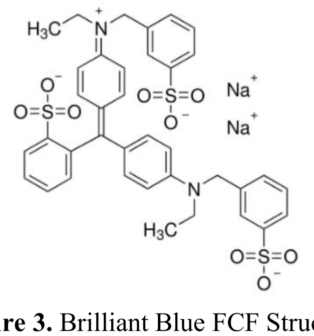

Figure 3. Brilliant Blue FCF Structure

Carmoisine is soluble in water, slightly soluble in an ethanol solution, but insoluble in vegetable oil. This dye is highly stable against pH, heat, light, and oxygen [3]. In addition to carmoisine, another synthetic dye that is legally available in Indonesia is Brilliant Blue FCF (CI. 42090). Brilliant Blue FCF has the chemical formula $C_{37}H_{34}N_2Na_2O_9S_3$ and is soluble in water [3]. Meanwhile, *Syzygium oleana* fruit extract is used as a natural dye. *Syzygium oleana* is a member of the *Myrtaceae* family. This plant is popular for its striking color and is commonly used as an ornamental plant [27]. The fruit of this plant is dark purple [28]. This fruit contains various anthocyanins, including cyanidin, delphinidin, petunidin, malvidin, and the unique compound peonidin. Although the leaves contain anthocyanins, their content in the fruit of the *Syzygium oleana* is much higher. This is why the fruit is much darker than the leaves [4]. The structure of anthocyanin compounds is illustrated in Figure 2.

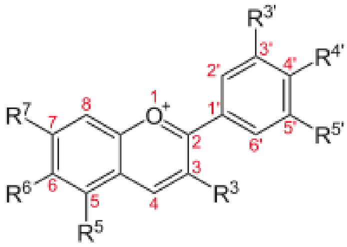

Figure 4. Anthocyanin Structure

TLC is performed to separate color pigments from samples based on differential partitioning between the stationary and mobile phases [17]. This technique enables the analysis and identification of pigments or compounds present in the sample. Generally, the equipment and materials used in TLC include a plate as the stationary phase, a developing chamber, and a solvent as the mobile phase. TLC plates can be made of glass, metal, or plastic coated with a thin layer of silica gel or alumina. The adsorbent material is a solid layer on a porous plate in TLC. The sorbent material (silica gel or alumina) is part of the stationary phase. Silica gel ($SiO_2 \cdot xH_2O$) on the TLC plate contains silanol groups (Si-OH). These hydroxyl groups can form hydrogen bonds and interact with compounds through dipole bonds, leading to separation [19]. Meanwhile, the mobile phase is a liquid solvent or a suitable solvent mixture. The mobile phase is also often referred to as the eluent. The solvent is selected based on the properties of the mixture to be separated. The requirements for the solvent to be used are high purity, cost-effectiveness, and non-reactive toward the sample or the stationary phase [29].

For the separation of synthetic purple dyes, ethanol, n-butanol, and water were used in various volume ratios as eluents. The TLC test results for synthetic purple food dyes showed that the samples separated into pink and light blue colors. The Rf values and polarity estimates for each variation in synthetic food dyes are shown in Table 5.

Table 5. TLC Result on Synthetic Food Coloring

No	Solvent Variation			Polarity Estimation	Spot Rf	
	Ethanol	n-butanol	Water		Pink	Blue
1	3	7	1	1.734 D	0.65	0.475
2	1	3	7	1.805 D	0.45	0.35
3	7	1	3	1.72 D	0.9	0.85
4	5	4	1	1.715 D	0.875	0.7
5	4	2	2	1.73 D	0.925	0.875

In Table 5, all TLC results separated the samples into two spots. This was due to the samples consisting of two components, namely Azorubine or carmoisine and Brilliant Blue FCF. Carmoisine (CI 14720), often known as azorubine, is a synthetic azo red dye. This dye is a disodium salt [3], [7]. Meanwhile, unlike azo dyes, Brilliant Blue is classified as a triphenylmethane dye [30]. The selection of a mixture of ethanol, n-butanol, and water as the mobile phase for separating synthetic purple dyes is based on their polarity toward the sample [1]. Both components, carmoisine and brilliant blue, have polar functional groups such as sulfonate and hydroxyl groups [3], [30]. When the sample is dropped onto the stationary phase, the mobile phase then moves upward on the plate via capillary action. At that point, the different components of the mixture move at different speeds, depending on the interaction between the stationary and mobile phases [31]. Based on the Rf values of the synthetic food color stains on Table 5, the blue stain is always less intense than the red stain. This indicates that the blue stain, Brilliant Blue FCF, is more polar than the red stain, carmoisine [17].

Based on the Rf values in Table 5, there are two mixtures with the same ΔRf, namely mixtures 1 and 4 with an Rf value of 0.175. However, the absolute Rf value is also crucial for evaluating the overall quality of the separation. Generally, the optimal range for separating a sample using TLC is when the Rf value obtained is between 0.2 and 0.6 [2]. If the value is too close to 0, it indicates that the component is moving sufficiently from the starting point. Meanwhile, if the Rf value is too close to 1, the element being separated moves too easily with the mobile phase [1]. In mixture 1, the Rf values of the pink and blue spots were 0.65 and 0.475, respectively. Both values are very close to the recommended range. This indicates that the dye components interact effectively with both the stationary and mobile phases, allowing the components to separate and spread well on the plate. Meanwhile, in mixture 4, the Rf values are 0.875 and 0.7, respectively. These values are higher and closer to 1. Although they are both separated by 0.175, spots near the solvent front may be compressed or less well defined, making the separation less visually clear compared to spots spread across the middle range. These findings are in line with a study conducted by Novitasari et al., who used the same eluent, a 7:3:1 ratio of ethanol, n-butanol, and water, to analyze the presence of synthetic red dyes in spinach samples. This eluent composition produced the good separation of the Rf range of standards in TLC experiments, although with a relatively long elution time of about one hour [1].

Meanwhile, this experiment used butanol, acetic acid, and water as the mobile phase for natural food coloring. In its application, the mobile phase was varied in different volumes. After performing TLC on the natural food coloring, the sample separated into two distinct colors: pink and a purplish-pink. The Rf values for each variation in the natural food coloring are presented in Table 6.

Based on Table 6, all eluents produced two pink and purplish pink spots, except for the last eluent. These colors are consistent with the theory that various shades of red, purple, and reddish brown will generally appear when separating anthocyanins using TLC [32]. Although two spots were produced, they were not separated by a distance. This is due to the sample components being very similar. The natural food coloring obtained from the extract of *Syzygium oleana* fruit contains various types of anthocyanins such as cyanidin, delphinidin, petunidin, malvidin, and the unique peonidin compound [4]. When the separated compounds are very similar, their polarities are also very similar, resulting in Rf values that are very close [33]. Eluent 5 produced only one spot, a pink gradient. This indicates no separation or that nearly all the sample compounds were eluted [29]. In chromatography, the greater the difference in Rf values between two bands (ΔRf), the better the separation is considered. From the Rf values, eluent 3 has the largest ΔRf (0.10), indicating that the anthocyanin band is separated most effectively from the contaminant band.

Table 6. TLC Result on Natural Food Coloringin

No	Solvent Variation			Polarity Estimation	Spot Rf	
	n-butanol	Acetic Acid	Water		Pink	Purplish-pink
1	4	1	5	1.799 D	0.82	0.76
2	1	5	4	1.785 D	0.84	0.76
3	5	4	1	1.756 D	0.8	0.7
4	6	2	2	1.768 D	0.72	0.67
5	4	4	2	1.766 D	0.47	0.47

Variations in the polarity of the mobile phase directly affect the retention factor (Rf) value. If the polarity of a mobile phase increases, the Rf value of TLC generally increases as well. This occurs because a more polar mobile phase has a stronger affinity for polar compounds, pulling them away from the polar stationary phase and causing them to move further up the TLC plate [19]. Determining the appropriate solvent system is the most influential factor in the TLC process. However, it is often considered the most challenging aspect [34]. The process of determining the optimal eluent can help develop students' scientific explanations. Determining the optimal eluent requires repeated experiments and testing different solvent compositions. This process requires students to design experiments, formulate hypotheses, and evaluate experimental results, including observing the size, number, shape, color of spots, and separation quality, as well as critically assessing the suitability of the eluent in the system. Explaining the observed Rf values and separation patterns in the selected eluent requires a detailed scientific explanation based on the relative affinity of the compound for the stationary phase and mobile phase, linking this affinity to the molecular structure and properties of the eluent [17]. By actively engaging in these steps, students move beyond describing the separation that occurred to explaining how and why the separation occurred [35]. This process makes their scientific more comprehensive, mechanistic, and grounded in fundamental chemical concepts [9]. It helps them construct causal-mechanistic explanation, which are essential for understanding chemical phenomena [35].

Development of Students' Scientific Explanation

The development of students' scientific explanation skills was measured using a scientific explanation test. This instrument was administered at the end of the learning process. It consists of nine questions designed according to the indicators of scientific explanation. The post-test for scientific explanation comprises nine essay questions, each aligned with the indicators, presented in a randomized order to assess students' understanding. The results of the scientific explanation assessment are shown in Table 7.

Table 7. Scientific Explanation Test Result

No	Scientific Explanation Aspect	Average	Category
1	Claim Analyzing the presented phenomenon	85	Very Good
2	Claim Conceptualizing a causal explanation	81	Very Good
3	Evidence Examining data, scientific facts, and disciplinary principles to refine causal explanations	72	Good
4	Evidence Discussing data and rewriting the causal explanation	79	Good
5	Reasoning Implementing causal-mechanistic knowledge to explain a phenomenon	76	Good
Average		79	Good

Scientific explanation is considered a fundamental skill that demonstrates an understanding of scientific inquiry and is particularly crucial in science education, especially in chemistry [36]. This ability comprises three aspects: claims, evidence, and reasoning. The first aspect or indicator is the claim. Students were asked to explain the strengths and weaknesses of using thin-layer chromatography (TLC) in analysis. With an average score of 85—categorized as good—students were deemed proficient in identifying and articulating clear and accurate responses to the given phenomena [12]. Furthermore, they were asked to construct claims that centered on conceptualizing causal explanations, delving into how and why phenomena occur by detailing underlying mechanisms [11]. This aspect was assessed through two questions: the first asked students to define TLC and explain how it works, while the second required them to describe how to calculate Rf values and their relevance in compound analysis. This aspect received an excellent rating, indicating that students not only stated what occurred but also began to form a conceptual understanding of the cause-and-effect relationships involved [12].

Moving to the evidence aspect, which involves discussing data and reconstructing causal explanations, students were asked to outline steps for separating components of synthetic and natural food colorants using TLC in a flowchart. They earned an average score of 72, classified as good. Next, students discussed data and rewrote their causal explanations. This aspect emphasized engagement with the presented data. The average score achieved was 79, also categorized as good. Students were also tasked with calculating Rf values based on the provided data. These scores broadly indicated that students could use data to support their explanations [11].

The final aspect is reasoning, where students apply causal-mechanistic knowledge to a phenomenon [12]. This was assessed through three questions, resulting in an average score of 76, which is considered good. These results suggest that students were able to explain how differences in the composition of the mobile phase led to varying values, select optimal solvent compositions for separating specific components, and effectively summarize their practical work. Although the reasoning is often identified as the most challenging component, the test results indicate that students have developed a strong capacity to articulate logical connections in their explanations [37].

Referring to Table 7, the test results indicate strong performance in scientific explanation skills, with an overall average score of 79, categorized as good. This suggests that students who were provided with guided inquiry-based worksheets were able to demonstrate their ability to formulate explicit claims, support them with evidence, and articulate the relationship between both through scientific reasoning. This reflects a more comprehensive understanding of component separation, namely, food colorants using TLC, compared to mere memorization [20], [38].

Conclusion

The implementation of guided inquiry-based worksheets in the TLC experiment, using both synthetic and natural food colorants, was carried out very well, with a learning implementation rate of 87%. The worksheets given to students yielded an average final score of 78, indicating that students were able to complete them successfully. Meanwhile, students' scientific explanation skills also developed well, as evidenced by an average score of 79 on the scientific explanation test. These results indicate that the application of guided inquiry learning through the TLC experiment, using both synthetic and natural food colorants, is practical in enhancing students' abilities to provide scientific explanations**.** Based on the positive outcomes observed from the implementation of guided inquiry-based worksheets in the TLC experiment, it is recommended that future research expand this approach to other analytical techniques such as High-Performance Liquid Chromatography (HPLC) and spectrophotometry. Additionally, incorporating a control group in future studies would strengthen the findings by allowing for comparison between guided inquiry-based learning and any other learning methods. This approach could help isolate the specific impacts of guided inquiry on student learning outcomes.

Author Contribution

Valen Dwike Sabila Nuraini: Writing, Original Draft, Methodology, Review, and Editing Investigation. Imelda Helsy: Review Supervision. Nurhayati: Review Supervision. Riri Aisyah: Instrument Validation. Yulia Sukmawardani: Instrument Validation.

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