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Development of an inquiry-based biology student worksheet based on the identification of Solanaceae plant trichomes for high school students

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Abstract. This study aims to develop an inquiry-based biology student worksheet that integrates research findings on identifying trichome variations in Solanaceae plants as a contextual learning resource. The study uses a Research and Development approach with the ADDIE model limited to the Development stage. The development stage includes drafting a student worksheet based on micrograph data from trichome observations, expert validation, and product revision. The study objects include chili, tomato, and eggplant leaves, which were observed under a light microscope at 100× magnification to identify the types and shapes of trichomes. The results of the study indicate the presence of non-glandular trichome variations, namely simple hairs with hooked ends on chili, simple needle-like hairs on tomatoes, and stellate-shaped trichomes on eggplant. These findings are integrated into the student worksheet during the problem analysis activity. Validation was carried out by two experts, covering content feasibility, presentation, language, and graphics, using a 1-4 Likert scale. The validation results after revision showed an average value of 3.54, which falls within a very eligible category. A student worksheet based on research into trichome variation was deemed conceptually eligible as an inquiry-based teaching material for biology. This study was limited to a feasibility test using expert judgment; further research is needed to assess the practicality and effectiveness of the student worksheet through classroom implementation.
Keywords: Inquiry learning, Students' worksheet, Solanaceae, Trichoma

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INTRODUCTION

Learning resources play a crucial role in biology education by bridging theoretical concepts and observable realities in the environment (Zahrudin & Pratiwi, 2024). As the study of living things and their interactions, biology requires students to not only understand the material textually but also to connect it to real-world phenomena (Arisandy et al., 2025). The use of relevant, authentic, and contextual learning resources can enhance conceptual understanding, minimize misconceptions, and foster curiosity (Sekarini & Arty, 2019). Furthermore, appropriate learning resources encourage active student involvement in the learning process through observation, experimentation, and analysis, thus optimally developing science process skills (Idris et al., 2022).

However, in biology instruction, many educators still rely on images in textbooks or digital materials that are generic and do not reflect real-world conditions. This makes it difficult for students to accurately visualize the form and function of biological structures, potentially leading to misconceptions (Kumandaş et al., 2019). Furthermore, the learning resources used are sometimes not contextualized to everyday life and do not utilize the abundant local potential, such as the diversity of flora and fauna around the school. As a result, learning becomes less meaningful, and students miss the opportunity to develop science process skills through direct observation, experimentation, and analysis of real objects (Suryawati & Osman, 2018).

One alternative to address the limitations of biology learning resources is to use realia, namely, real objects that students can observe and study directly. Realia media encourages students to interact directly with biological phenomena, allowing them to observe form, structure, texture, and function more authentically (Salsabila et al., 2025). One example of potential realia media is plants from the Solanaceae family, such as tomatoes (*Solanum lycopersicum*), chili peppers (*Capsicum frutescens*), and eggplants (*Solanum melongena*). These plants are easily found in the surrounding environment, allowing students to directly observe the variety of trichomes they possess (Mardhiyah et al., 2024).

Trichomes are protrusions, or hairs, that originate from the epidermal cells of plants and can be found on various organs, such as leaves, stems, flowers, and fruit. These structures vary in shape, size, and function depending on the plant type and species (Wang et al., 2019). In general, trichomes are divided into two main types: glandular trichomes that produce secretions such as essential oils, mucus, or defense compounds (Muravnik, 2021), and non-glandular trichomes that provide mechanical protection against physical disturbances or herbivory (Karabourniotis et al., 2020). The presence and variety of trichomes are often characteristic of a species and can therefore be used as taxonomic characters in plant classification. Furthermore, trichomes also have important ecological functions, such as reducing transpiration rates, reflecting solar radiation, and helping plants adapt to extreme environmental conditions (Bickford, 2016). In the Solanaceae family, trichomes are generally easy to observe and exhibit interesting variations in shape, making them potential objects for microscopic observation in contextual biology learning (Dewi et al., 2015).

Extensive research has been conducted on plant trichomes, examining their anatomy, morphology, taxonomy, and physiology. Several studies report variations in trichome types in the Solanaceae family as important diagnostic characteristics for species and variety identification (Dewi et al., 2015; Mardhiyah et al., 2024). For example, research by Dewi et al. (2015) showed that trichomes on Solanaceae leaves can be classified into several types based on their shape and gland presence, which can be used as distinguishing characteristics between species. Another study by Mardhiyah et al. (2024) revealed that glandular trichomes in Solanaceae secrete defense compounds, whereas non-glandular trichomes primarily serve as physical protection.

The use of plant anatomy research results as an integrated learning resource in teaching materials is still limited. Until now, learning has relied more on textbooks and general two-dimensional illustrations, preventing students from gaining empirical evidence-based learning experiences through observation of real objects (Khumairo, 2015). Consequently, the interconnectedness of biological concepts has not been fully understood, and science process skills have not yet been developed optimally. Therefore, to facilitate biology learning and achieve both conceptual understanding and process skills, teaching materials that facilitate inquiry activities are needed (Masithah et al., 2022).

Therefore, it is necessary to develop Student Worksheets that utilize research findings on the identification of trichome variation in Solanaceae plants as a basis for developing inquiry-based learning activities. Based on previous research, inquiry-based student worksheets can encourage students to actively engage in the scientific process through the stages of formulating problems, proposing hypotheses, conducting microscopic observations, collecting and analyzing data, and drawing conclusions based on empirical evidence (Masruhah et al., 2022). Furthermore, developing experiment-based student worksheets effectively improves student understanding because it optimizes learning by meaningfully integrating theory and practice (Akmala et al., 2025). Integrating research findings into teaching materials can improve science process skills and student learning outcomes (Anggrella et al., 2020). Based on previous research, little work has been done to develop an inquiry-based student worksheet integrated with research findings. Therefore, it is necessary to

develop a student worksheet that is not only aligned with learning models but also grounded in real-world research findings, so that biology learning becomes more contextual, meaningful, and relevant to students' environments.

METHOD

Research design

This is a research and development (R&D) project aimed at producing inquiry-based biology worksheets. The development model used is an adaptation of the ADDIE model (Branch, 2009), but the research was limited to the development stage due to time and resource constraints. The development stage included drafting the worksheet based on research identifying variations in Solanaceae plant trichomes, expert validation, and product revision based on validator input.

This research assesses the feasibility/validity of the content through expert judgment, thereby demonstrating the product's conceptual feasibility. This study has not yet tested the worksheet's practicality and effectiveness through field trials with students. Therefore, classroom implementation and the measurement of impact on learning outcomes are recommended as further research stages.

ADDIE model development procedure

Analysis

The analysis stage was conducted to identify: 1) the need for learning resources on the topic of plant epidermis tissue for high school students; 2) the suitability of trichome research results as contextual learning materials; 3) student characteristics and the demands of Biology learning competencies. In addition, a literature review on plant anatomy was conducted to identify indicators for trichome identification.

Design

The design stage includes: 1) developing competency-based learning objectives; 2) designing an inquiry-based student worksheet structure; 3) developing steps for observing trichomes; 4) designing a student worksheet validation instrument. The student worksheet is designed to include activities aligned with the inquiry syntax used, including inquisition, acquisition, supposition, implementation, summation, and exhibition (Lliwellyn, 2013).

Development

Trichome identification research

The research subjects were plant leaves from the Solanaceae family collected from the UIN Raden Mas Said Surakarta campus. Sampling was conducted in the morning of April 2025 (7:00–9:00 a.m. Western Indonesian Time) to minimize variation in leaf physiological conditions. Samples were selected using purposive sampling, encompassing three readily available species that represent a variety of trichome structures: chili pepper leaves (*Capsicum frutescens*), tomato leaves (*Solanum lycopersicum*), and eggplant leaves (*Solanum melongena*).

For each species, three leaves from different plants were used, and three slides were prepared per leaf (a total of nine slides per species). Inclusion criteria included fresh leaves from the middle of the canopy, normal green color, and freedom from pests, diseases, and mechanical damage. Observations were made on both leaf surfaces (adaxial and abaxial) during the initial exploration phase. However, reporting of results focused on the surface with the clearest trichome morphology on the slide for each species to maintain the quality of comparative documentation.

The tools and materials needed for trichome identification are: 1) Tools: light microscope, object glass, cover glass, tweezers, scissors, digital camera/cell phone, stationery, magnifying

lens; 2) Materials: fresh leaves from each Solanaceae species, namely Chili Leaves (*Capsicum frutences*), Tomato Leaves (*Solanum lycopersicum*), Eggplant Leaves (*Solanum melongena*).

The research procedure begins with: 1) taking samples in the form of fresh leaves from plants of the Solanaceae family; 2) Preparations are made by cutting the edge or surface of the leaf using a razor blade, then the leaf pieces are placed on a glass object, dripped with distilled water, and covered with a cover glass; 3) Preparations are observed using a light microscope with a 10× eyepiece and a 10× objective (total magnification of 100×) to identify the shape and type of trichomes based on plant anatomy literature; 4) Observation results are documented by photographing the object using a microscope camera; 5) The final stage is data processing and classification by grouping the types of trichomes based on glandular and non-glandular criteria.

Development of student worksheet

The results of the trichome variation identification were used as a learning resource and then packaged into inquiry-based teaching materials. The resulting product was validated by two validators (n = 2), consisting of (1) a material expert in plant anatomy (a biology lecturer with ≥5 years of teaching experience) and (2) a teaching materials expert in learning technology (a teaching materials development lecturer with ≥5 years of experience). The selection of validators was carried out purposively based on the suitability of their expertise to the material's substance and the development of the learning tools.

The assessment used a 1-4 Likert scale validation instrument covering four aspects: content appropriateness (8 items), presentation appropriateness (7 items), language appropriateness (5 items), and graphic appropriateness (6 items). The validators' input and suggestions were used as the basis for revisions to improve material clarity, presentation systematics, language accuracy, and display quality.

Student worksheet is compiled following the syntax of the inquiry model which includes the stages of inquisition (stating a question to be investigated), acquisition (brainstorming possible solutions), supposition (selecting a statement to test), implementation (designing and carrying out a plan), summation (collecting evidence and concluding), and exhibition (sharing and communicating results) (Lliwellyn, 2013), and is adapted to the use of communicative language that is easy for students to understand.

Data analysis techniques

Data from trichome documentation were analyzed descriptively and qualitatively by comparing the observations with plant anatomy references from Khan et al. (2021) and Shivashankar & Urziversiv (1992). Identification results are presented in tables, photographs, and morphological descriptions of trichomes for each species. The potential of the research results as learning resources is packaged as a student worksheet, teaching materials, and glass specimens (trichome preparations). The student worksheet was validated by experts with competence in teaching materials and Plant Development Structure. Aspects assessed for content validity include content suitability, presentation suitability, language suitability, and graphical suitability. The assessment criteria are presented in Table 1.

Table 1. Student worksheet assessment criteria

Score Range	Description
$X \geq Xi + 1.Sbi$ = $X \geq 3,0$	Very Eligible
$Xi + 1.SBi > X \geq Xi$ = $3,0 > X \geq 2,5$	Eligible
$Xi > X \geq Xi - 1.Sbi$ = $2,5 > X \geq 2,0$	Quite Eligible
$X < Xi - 1.Sbi$ = $X < 2,0$	Not Eligible

Sumber: (Mardapi, 2008)

RESULTS AND DISCUSSION

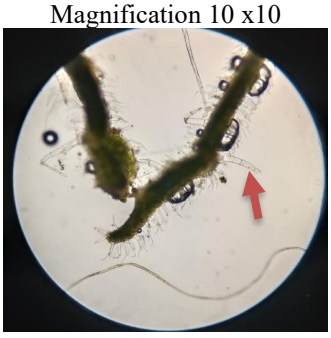
Results of research on the identification of Solanaceae trichomes

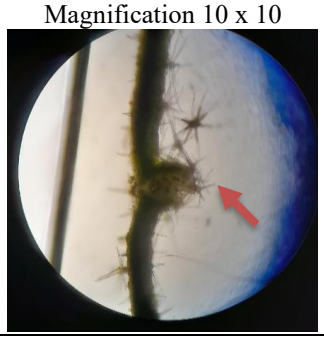
This study aims to identify the types of trichomes in plants belonging to the Solanaceae family. The research objects consist of three plant types: chili leaves (*Capsicum frutescens*), tomatoes (*Solanum lycopersicum*), and eggplant (*Solanum melongena* L.). The results of observations of trichomes in the Solanaceae family were then prepared as microscopic slides that can serve as a biology learning resource, as they present real objects for students to observe directly. Furthermore, the results of the observation documentation were developed into Student Worksheets, which function as teaching materials to guide learning activities. By combining preparations as learning resources and student worksheets as teacher teaching materials, this study not only produces plant anatomy data but also contextual and applicable learning products to support students' science process skills.

Trichome identification

Based on the morphological classification used in the research method, following Shivashankar & Urziversiv (1992) and Khan et al. (2021), all observed trichomes were non-glandular, and glandular trichomes were not found in the observed preparations. The absence of glandular trichomes is influenced by several factors, including environmental conditions, hormones, and genetic regulatory mechanisms, such as transcription factors and non-coding RNAs that play roles in trichome initiation, branching, and growth (X. Wang et al., 2021). The results of observations of leaf preparations from three plant species of the Solanaceae family showed variations in trichome shape on the leaf surface, as presented in Table 2.

Table 2. Summary of trichome types found in the Solanaceae family

No	Species of the Solanacea family	Trichomes Types	Trichome Shape	Figure
1.	*Capsicum frutescens [Abaxial]*	Non-Glandular	Simple hooked-end hair	Figure 1. *Capsicum frutescens* Magnification 10 x10 
2.	*Solanum licopersicum [Adaxial]*	Non-Glandular	Simple hair that resembles a needle	Figure 2. *Solanum licopersicum* Magnification 10 x10 

No	Species of the Solanacea family	Trichomes Types	Trichome Shape	Figure
3.	*Solanum melongena [Adaxial]*	Non-Glandular	Stellata	Figure 3. *Solanum melongena* Magnification 10 x 10 

Based on Table 2, observations of trichomes on the leaves of Solanaceae plants were conducted using a light microscope at 100× magnification (10× ocular × 10× objective). Observations focused on the leaf surface that displayed the clearest trichome morphology in each species' preparation. In *Capsicum frutescens* leaves, the abaxial surface showed simple hair-like non-glandular trichomes with hooked tips. In *Solanum lycopersicum* leaves, the adaxial surface was dominated by simple hair-like non-glandular trichomes. Meanwhile, in *Solanum melongena* leaves, the adaxial surface exhibited stellate (star-shaped) non-glandular trichomes. All observations were documented at 100× magnification as visual evidence of the differences in trichome shape in the three species. These findings demonstrate the diversity of trichome structures within a single family that can be used as real objects for learning plant anatomy.

Types of trichomes

On the abaxial surface of chili leaves, simple hair-like trichomes with hooked tips were found. According to Shivashankar & Urziversiv (1992), the trichomes found were non-glandular. This structure serves as mechanical protection, as the hooked tips deter herbivorous insects from damaging leaf tissue. Furthermore, the simple hairs also help reduce transpiration by creating a barrier on the leaf surface (Kaur & Kariyat, 2020). This suggests that chili trichomes play an important role in plant defense mechanisms against both biotic and abiotic factors (Nor & Shaipulah, 2021).

On the adaxial surface of tomato leaves, simple hair-like trichomes were observed; according to Shivashankar & Urziversiv (1992), these trichomes were non-glandular. These structures are relatively thin and elongated, making them more effective in suppressing transpiration and protecting the leaves from excessive solar radiation. Furthermore, the needle-like shape makes it difficult for small insects to move on the leaf surface. The presence of these trichomes demonstrates a morphological adaptation that helps tomatoes retain moisture and resist external disturbances (Popowski et al., 2025).

Observations on the adaxial surface of eggplant leaves revealed the presence of stellate-shaped non-glandular trichomes (branched like a star). Shivashankar & Urziversky (1992) reported stellate, non-glandular trichomes with numerous arms, averaging 7-8. This research finding aligns with Dewi et al. (2015), who stated that the genus Solanum melongena possesses stellate-shaped non-glandular trichomes. These stellate trichomes have wide branches, allowing them to cover a larger leaf surface area than simple trichomes. Their primary function is to protect against high levels of sunlight, reduce water loss, and provide stronger physical defense against insects (Katinas, 2025). This unique stellate shape makes eggplant trichomes more prominent morphologically than those of chili peppers and tomatoes.

Research results for developing student worksheets

Analysis stage

The results of the needs analysis indicate that learning about the structure and function of plant tissue in high school is still dominated by textbooks and two-dimensional images, so student involvement in direct observation activities remains limited. The material on plant epidermis, especially trichomes, has great potential as a subject for contextual microscopic observation and is readily found in the surrounding environment. The results of the curriculum study indicate that learning competencies require students to relate the structure of plant tissue to its function and role in life. Therefore, research-based learning resources are needed that enable students to conduct direct scientific observations. Analysis of student characteristics shows that inquiry-based learning with simple practical activities is suitable for practicing science process skills, such as observation, classification, and conclusion. This student worksheet is based on research on the identification of trichome variations in Solanaceae plants using an inquiry approach, thereby supporting scientific observation-based learning and science process skills, as shown in Figures 4 and 5.

Design stage

In the design stage, an inquiry-based student worksheet was prepared to integrate findings from research on identifying trichomes in the Solanaceae family. The student worksheet structure was designed to include: inquisition, acquisition, supposition, implementation, summation, and exhibition (Lliwellyn, 2013). In addition, learning indicators, practical activity instructions, observation sheets, and student worksheet validation instruments were developed.

Development stage

The development of the Student Worksheet in this study comprised initial product drafting, expert validation, and product revision. During the drafting stage, the results of the trichome variation identification research were integrated as a learning resource and packaged into an inquiry-based student worksheet. The student worksheet structure was structured according to the syntax of inquiry learning and aligned with the learning objectives and learning outcomes in the science process skills element.

According to Figure 4, the developed student worksheet integrated research findings on trichome variation in Solanaceae plants as a contextual learning resource. The initial section of the student worksheet presents the learning objectives, contextual problems, and scientific information as research data demonstrating differences in trichome shape across several species. The presentation of research data in tables and microscopic images provides an empirical, evidence-based learning experience, providing students with a scientific foundation before engaging in inquiry activities. This structure demonstrates that the student worksheet serves not only as a guide for activities but also as a learning medium that connects theoretical concepts with actual research findings.

Furthermore, as shown in Figure 5, the student worksheet facilitates an inquiry-based learning process through systematic stages of activity: formulating questions, gathering information through observation, formulating hypotheses, analyzing results, drawing conclusions, and communicating findings. Each stage is equipped with a workspace that encourages active student involvement in the scientific inquiry process. The analysis section directs students to compare observation results with research data. In contrast, the conclusion section requires students to synthesize information to understand the relationship between variations in trichome shape and their biological functions. The communication stage of results also shows that the student worksheet supports the development of scientific argumentation skills and scientific literacy.

Figure 4. The student worksheet developed contains objectives, problems, scientific information (based on research results), and inquiry activities: inquisition (stating a question to investigate), acquisition (brainstorming possible solutions), and supposition (selecting a statement to test).

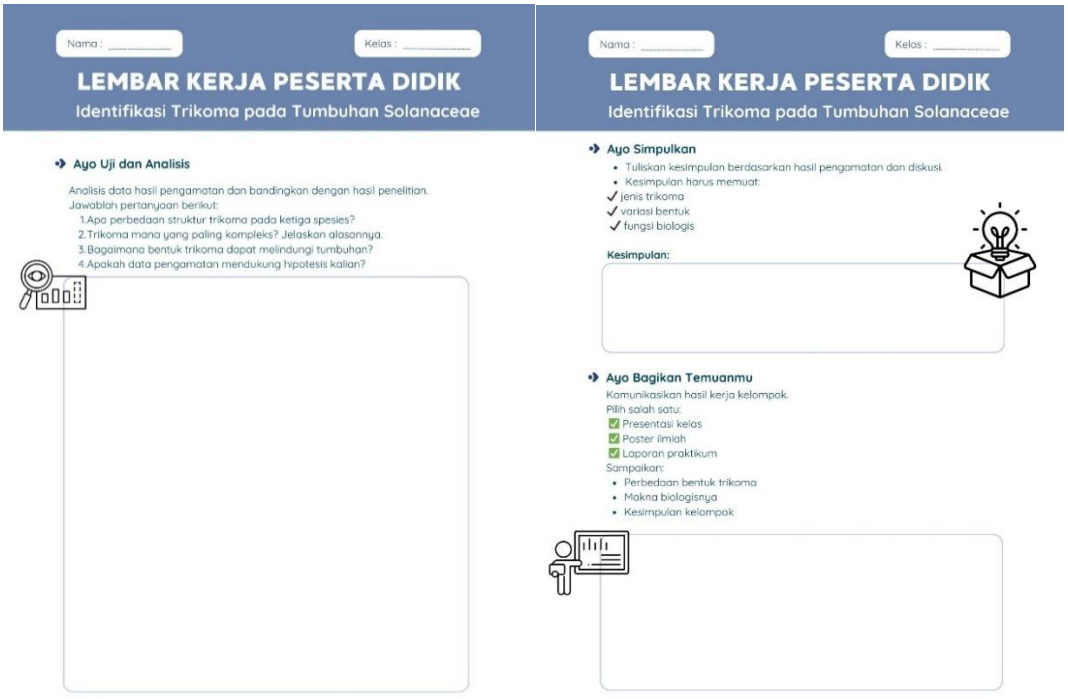


Figure 5. The developed student worksheet includes the inquiry stages of implementation (designing and carrying out a plan), summation (collecting evidence and concluding), and exhibition (sharing and communicating results).

Student worksheet validation

Student worksheet validation was conducted by 2 validators, consisting of: (1) a plant anatomy lecturer with ≥5 years of teaching experience, (2) a learning technology lecturer

specializing in teaching materials development. The assessment used a 1-4 Likert scale for the aspects of content suitability, presentation, language, and graphics. The validator's input was used to revise the product, making the student worksheet more systematic and communicative. The validation results are presented in Table 3.

Table 3. Results of student worksheet validation by experts after revision

Aspects	Before revision	After revision	Criteria
Content suitability	2,4	3,63	Very Eligible
Presentation suitability	2,2	3,58	Very Eligible
Language suitability	3	3,50	Very Eligible
Graphic suitability	3,2	3,45	Very Eligible
Average	2,7	3,54	Very Eligible

Based on the feasibility criteria with Xi = 2.5 and SBi = 0.5, as shown in Table 1, all assessment aspects after the revisions in Table 3 received a score of ≥3.0, thereby categorizing them as highly eligible. The overall average score of 3.54 indicates that the developed worksheet is conceptually very eligible based on expert assessment.

The results of expert validation of the worksheet on identifying trichomes in Solanaceae plants indicate an improvement in product quality after revisions based on the validator's suggestions. The assessment was conducted on four main aspects: content feasibility, presentation feasibility, language feasibility, and graphic feasibility. Prior to the revision, the worksheet included the basic components of practical learning, but several weaknesses still affected the direction of the scientific process. Regarding content feasibility, the observation material did not fully demonstrate the relationship between trichome structure and its biological function, thus not optimally facilitating students' conceptual understanding. Regarding presentation feasibility, the flow of activities did not fully reflect the systematic stages of inquiry, thus not optimally guiding students in the scientific investigation process. In terms of language, some activity instructions were still general and potentially open to multiple interpretations. Meanwhile, the worksheet's graphical presentation was deemed quite neat but lacked visual cues to support the observation process.

After revision, the worksheet demonstrated improvements across all assessment aspects and aligned with the principles of expert evaluation-based development in the ADDIE model (Branch, 2009). Regarding content adequacy, the worksheet was supplemented with research-based scientific information and examples of trichome shape variations, strengthening the conceptual foundation of learning and helping students relate structure to its biological function. This enhanced content provided an empirical context that supported meaningful learning through real-world data, in line with the importance of conceptual accuracy in the study of plant anatomy (Fahn, 1990). In terms of presentation, learning activities were structured more systematically, following the stages of guided inquiry, starting with inquisition (stating a question to be investigated), acquisition (brainstorming possible solutions), supposition (selecting a statement to test), implementation (designing and carrying out a plan), summation (collecting evidence and concluding), and exhibition (sharing and communicating results). This coherent activity structure guides students through the scientific process and constructs knowledge through direct experience (Lliwellyn, 2013). Therefore, the Student Worksheet serves not only as a practical work tool but also as a means of developing scientific thinking skills (Suryawati et al., 2015). Previous research has shown that inquiry-based student worksheets can improve critical thinking and student learning outcomes (Firdaus & Wilujeng, 2018).

From a linguistic perspective, the activity instructions are clarified and use scientific terminology consistently, supporting independent practical work and minimizing errors in observation procedures. Graphically, the student worksheet display becomes more informative

through the addition of illustrations of observation results and a more proportional workspace arrangement. These visual enhancements serve as observational stimuli that help students recognize objects more accurately, demonstrating that integrating text and visuals plays a crucial role in enhancing conceptual understanding (Mayer, 2002).

Furthermore, the learning objectives in the revised Student Worksheet align with the learning outcomes for the science process skills element. The series of activities is designed to facilitate students in conducting systematic observations, collecting and recording data, identifying structural variations, formulating hypotheses, interpreting observational results, and drawing conclusions based on empirical evidence. The integration of objectives, activities, and learning outcomes reflects the characteristics of inquiry-based learning, which places direct experience as the foundation for constructing scientific knowledge (Lliwellyn, 2013). Based on the validation results and analysis of improvements, the revised Student Worksheet was deemed suitable for use as an inquiry-based learning tool that supports the development of science process skills in biology.

This research, based on the results of the study on trichome variation in Solanaceae plants, has limitations in the development stages. The development process follows the ADDIE model, but the research only reached the development stage and has not yet progressed to the implementation and evaluation stages. Therefore, the developed Student Worksheet has not been tested through field trials, either on a small or large scale. The absence of an implementation phase means that the effectiveness of the student worksheet in improving students' learning outcomes and science process skills cannot be empirically determined. Furthermore, the study has not yet collected data on the practicality of student worksheet use, student responses, or classroom learning implementation. The results of this study are still limited to an assessment of product feasibility based on expert validation, so further research is needed to test the practicality and effectiveness of the student worksheet through direct implementation and learning evaluation across various trial scales.

CONCLUSION

This study identified variations in the shape of non-glandular trichomes in the leaves of plants in the Solanaceae family, including simple hairs with hooked tips on chili peppers, simple needle-like hairs on tomatoes, and stellate trichomes on eggplants. These structural variations indicate morphological characteristics that may contribute to plant tissue protection and environmental adaptation. The results of microscopic observations were then used to develop inquiry-based student worksheets integrated into the problem analysis. Based on expert validation, the developed student worksheet received an average score of 3.54, categorized as very eligible. The student worksheet was deemed appropriate in content, presentation, language, and graphics, making it suitable for use as a conceptual, inquiry-based biology learning tool. Further research is recommended to test the practicality and effectiveness of student worksheets through classroom implementation to obtain empirical evidence of their impact on students' science process skills and conceptual understanding.

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