Journal of Turkish Science Education, 2024, *21*(3), 533-548.
DOI no: 10.36681/tused.2024.028

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Enhancing prospective biology teachers' critical analysis skills: an evaluation of plant anatomy and development textbook effects

Herdiyana Fitriani[1], Muhammad Asy'ari[2], Siti Zubaidah[3], Susriyati Mahanal[4], Taufik Samsuri[5]

[1]*Universitas Pendidikan Mandalika, Indonesia, ORCID ID: 0000-0002-8947-1276*
[2]*Universitas Pendidikan Mandalika, Indonesia, Corresponding author, muhammadasyari@undikma.ac.id, ORCID ID: 0000-0002-3149-3296*
[3]*Universitas Negeri Malang, Indonesia, ORCID ID: 0000-0002-0718-6392*
[4]*Universitas Negeri Malang, Indonesia, ORCID ID: 0000-0001-5764-2184*
[5]*Universitas Pendidikan Mandalika, Indonesia, ORCID ID: 0000-0002-4464-4938*

ABSTRACT
Critical analysis (CA) skills are crucial in higher education and should be incorporated into the curriculum at that level. The unique characteristics of abstract biology materials and the involvement of prospective Biology teachers (PBTs) in scientific investigation activities make them highly relevant for teaching CA skills. Inquiry activities require teaching materials or textbooks that explicitly engage science teacher trainees in science process skills (SPS) activities. For effective inquiry-based learning (IBL), appropriate textbooks are essential. Therefore, in this study, a Plant Anatomy and Development textbook based on SPS was utilized as a tool to develop CA skills. The main objective of the study was to assess the impact of SPS-based PADT on PBTs' CA skills in the Plant Anatomy and Development (PAD) course. To achieve the research objectives, a quasi-experimental research design with a pretest-posttest control group was implemented. The research sample consisted of fifty-five prospective teachers who were selected through purposive sampling. They were divided into two groups: the experimental group (n=28) and the control group (n=27). To analyze the students' critical analysis skills, twelve valid and reliable essay items were utilized. The research findings indicated that the experimental group exhibited a significantly greater cognitive gain (>0.70) compared to the control group (0.30 < n-gain < 0.70) ($p < 0.05$).

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
02.01.2023
Accepted:
30.10.2023

KEYWORDS:
Textbook, plant anatomy and development, science process skills, critical analysis skills.

To cite this article: Fitriani, H., Asy'ari, M., Zubaidah, S., Mahanal, S., & Samsuri, T. (2024). Enhancing prospective biology teachers' critical analysis skills: an evaluation of plant anatomy and development textbook effects. *Journal of Turkish Science Education*, *21*(3), 533-548. DOI no: 10.36681/tused.2024.028

Introduction

The learning process in higher education places significant emphasis on the active transfer of information (Hamouda & Tarlochan, 2015; Hincapié Parra et al., 2018) and autonomous cognitive aspects (Guo & Wang, 2021; Mystakidis et al., 2019) in order to enhance the thinking skills of prospective teachers (Heijltjes et al., 2015). However, thinking skills cannot be acquired simultaneously, and they are typically viewed as a byproduct of learning in general (Davies, 2013). Consequently, specific learning activities targeting thinking skills are necessary (Halpern, 2014).

Additionally, there is still ongoing debate regarding the most effective approaches for teaching these skills (Davies & Barnett, 2015; Tiruneh et al., 2014). Critical analysis is considered one of the crucial thinking skills that need to be cultivated (Fitriani et al., 2019), alongside problem-solving, effective communication, collaboration, creativity, and innovation (Christian et al., 2021).

The primary objective of the present study is to investigate the efficacy of scientific-inquiry-oriented learning, specifically when accompanied by teaching materials that actively engage prospective teachers in scientific investigations (Kruit et al., 2018; Lazonder & Harmsen, 2016). Additionally, the study aims to address the imperative of enhancing critical thinking (CT) abilities, as previously discussed. While numerous studies have explored the utilization and effectiveness of inquiry-based learning (IBL) in fostering CT skills (Davenport Huyer et al., 2020; Pahrudin et al., 2021; Rusmansyah et al., 2019), there exists a gap in assessing the impact of the Plant Anatomy and Development Textbook (PADT) and its implementation in IBL for the enhancement of prospective biology teachers' (PBTs) CT skills.

A number of empirical studies have demonstrated the significance of acquiring critical analysis skills (Haerazi et al., 2021; Karantzas et al., 2013; Wale & Bishaw, 2020). Unfortunately, students tend to exhibit limited improvement in their thinking skills (Flores et al., 2012; Pascarella et al., 2011), particularly in critical analysis (CA) skills (Fitriani et al., 2019a) during their college and post-college years (McLaughlin et al., 2014). This situation leads to numerous instances of college graduates facing difficulties in employment due to their lack of thinking skills (Alsaleh, 2020; Arum et al., 2012), including CA skills. In today's digital era (Klimova, 2013), where the verification of information is crucial (Haug & Mork, 2021; Knight & Horsley, 2013; Pantò & Comas-Quinn, 2013; Spector & Ma, 2019), CA skills are indispensable. However, several authors argue that the teaching of CA skills is inconsistent (Sotiriadou & Hill, 2015) due to teachers' or lecturers' limited knowledge about the subject (Fitriani et al., 2019), the belief that conceptual knowledge alone guarantees success in employment (Wale & Bishaw, 2020), and the lack of teaching materials explicitly designed to enhance students' CA skills (Barsoum et al., 2013; Mena, 2019).

The SPS-based PADT utilized in this investigation has been demonstrated to possess validity and reliability (r=0.77) with regards to its content and construct (Fitriani et al., 2019a). Nevertheless, its effectiveness in relation to CA skills has not been previously examined. The PAD course possesses abstract characteristics and tends to be experimental, focusing on the structure and development of seed plants. The PADT, which was developed based on SPS, encompasses a variety of topics, including cell structure and development, tissues, and reproductive organs. The objective of this study is to evaluate the impact of SPS-based PADT on the CA skills of PBTs. In this study, CA skills are defined as the ability to break down information into smaller components in order to attain a more comprehensive understanding. This is measured through indicators such as organization, association, interpretation, evaluation, reflection, and decision-making. The two research questions guiding this study are: (1) What is the effectiveness of SPS-based PADT in enhancing the critical analysis skills of prospective Biology teachers? and (2) How does the implementation of SPS-based PADT influence the development of Critical Analysis (CA) skills among prospective Biology teachers?

Literature Review

Analyzing problems requires cognitive skills to break down information or knowledge into smaller parts in order to gain a comprehensive understanding (Anderson & Krathwohl, 2001; Muhali et al., 2021). Critical analysis is developed through cognitive strategies that aim to guide appropriate decision-making (Ennis, 2018). This is done by considering the strengths and weaknesses of different alternative strategies and the resulting needs (Facione, 2020; Muhali et al., 2019). Critical analysis involves organizing information, making connections between the different parts or variables in the information (association), interpreting data, reflecting on the evaluation process, and making decisions based on formulated concepts and problem-solving (Fitriani et al., 2019b).

Critical analysis is related to both critical thinking and problem-solving (Brookhart, 2010; Karantzas et al., 2013), which are essential for accurately interpreting information (Sotiriadou & Hill, 2015). The connection between critical analysis and the enhancement of cognitive skills and the facilitation of effective problem-solving is becoming increasingly clear, given the significant role that critical analysis plays in these areas. Therefore, it is crucial for individuals to actively engage in extensive educational pursuits that embrace the principles of critical analysis. This will enable them to acquire the necessary skills to effectively analyze information and make well-informed judgments (Eggen & Kauchak, 2012; Fisher, 2011; Fitriani et al., 2019b; Woolfolk Hoy et al., 2013).

Critical thinking and problem-solving abilities are essential skills that students must acquire during their higher education. These skills are crucial for future educators as they help them comprehend the connection between scientific theory and practical application (Thomas, 2011). Additionally, these skills equip educators to address novel and ambiguous problems (Caesar et al., 2016) and promote active communication and collaboration (Heritage et al., 2016; Morris et al., 2013).

While the theoretical foundations of critical thinking (CT), creative thinking (CA), and problem-solving may seem distinct (Fitriani et al., 2019a), these concepts are intricately intertwined (Karantzas et al., 2013). Critical thinking involves a range of skills, including interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2020). It is used to assess ideas and problem-solving strategies, leading to decision-making related to strategy selection, refinement, and practical application (Ennis, 2018; Ruggiero, 2015). The development of critical thinking requires procedural activities such as organizing, associating, interpreting data, evaluation, reflection, and decision-making (Fitriani et al., 2019a). These activities are also fundamental components of creative thinking and problem-solving.

A textbook holds significant importance as a tool for effective learning (Dancy et al., 2016). It has the potential to enhance learners' competence and effective communication when implementing learning models or strategies (Hidayatulloh et al., 2020; Knight, 2015). Textbooks play a crucial role as a source of learning for students (Barsoum et al., 2013; Mena, 2019), particularly in the field of Biology, where knowledge formation and the development of scientific attitudes are emphasized through experimental activities (Sormunen & Serdar, 2014). Textbooks that incorporate scientific process skills (SPS) serve as valuable learning resources and mentors for students, connecting procedural, factual, conceptual, and metacognitive knowledge (Madsen et al., 2016). SPS is a skill that students should acquire through active scientific investigation, by posing and answering questions (Asy'ari, Fitriani, et al., 2019; Lee, 2014). The Plant Anatomy and Development textbook, which is grounded in scientific process skills (SPS), provides comprehensive instructional materials and guidelines. It effectively integrates SPS to assist instructors in fostering students' scientific abilities and promoting interactive and student-centered learning experiences. Additionally, it aids students in comprehending complex concepts related to plant anatomy and development (Fitriani et al., 2019b).

The integration of SPS in the materials of the Plant Anatomy and Development textbook assists prospective teachers in conducting simple observations/experiments, discovery, problem analysis, problem-solving, and communication of new knowledge. Scientific activities are presented in the form of exploration worksheets, while questions help develop students' critical analysis skills. In line with this, Holmes et al. (2021) assert that textbooks should incorporate the principle of visible learning or evidence-based learning to address various aspects of students' learning, such as attention, memory, and executive control (planning and problem-solving), in order to foster their cognitive skills and engage in critical analysis.

Learning emphasising SPS is the best way to train thinking skills (Rönnebeck et al., 2016; Sambudi et al., 2023) because it involves prospective teachers directly in scientific reasoning, compiling experimental procedures, data interpretation, and critical thinking (Schallert et al., 2020; Wirzal, Halim, et al., 2022). SPS consists of two categories, i.e., basic SPS and integrated SPS (Aktamış & Yenice, 2010; Bulent, 2015). Basic skills including observation, classification, communication, measurement, prediction, and inference, while integrated skills including variable identification, data table preparation, graphing, describing relationships between variables, data acquisition and data processing, analytical investigations, hypothesis formulation and variable definition operational (Asy'ari, et al., 2019). The integrated SPS particularly is necessary to conduct an investigation to solve problems (Lazonder & Egberink, 2014). However, prospective teachers did not understand SPS clearly (Asy'ari et al., 2019; Durmaz & Mutlu, 2017) and so it has a low impact on their CA-skills (Fitriani et al., 2019b).

Methods

Research Design

A quasi-experimental research study was conducted to assess the impact of SPS-based PADT on the critical analysis skills of PBTs. The study utilized a pretest-posttest control group design, as described by Fraenkel et al. (2012). The posttest data from both the experimental and control groups were analyzed to achieve the objectives of the research. The sample underwent six meetings, during which pretest and posttest data were collected at the beginning and end of each meeting, respectively. The pretest data of the sample were employed as a covariate to account for any initial variations in the critical analysis skills of the PBTs who participated in the study. Table 1 provides an illustration of the research design.

Table 1

Research design

Group	Pretest	Treatment	Posttest
Experimental	CAS test	Inquiry-based with SPS based-PADT	CAS test
Control	CAS test	Conventional	CAS test

Research Sample

The participants in this study were selected from the biology education programme at Universitas Pendidikan Mandalika. Specifically, the sample consisted of prospective Biology teachers who were enrolled in the Plant Anatomy and Development course during the even semester of 2021/2022. The total number of participants was 55, divided into two groups: the experimental group (n= 28, male= 11, female= 17, age= 20) and the control group (n= 27, male= 12, female= 15, age= 20).

Instrument and Procedure

The critical analysis skills of BPT were evaluated through twelve essay items. The instrument demonstrated a content validity of 3.83 and a construct validity of 3.87. Moreover, it exhibited high reliability, with a content reliability of 0.97 and a construct reliability of 0.98 (Cronbach's Alpha: 0.78) (Fitriani et al., 2019a).

The instruments were utilized to evaluate the initial critical analysis skills of pre-service biology teachers (PBTs) through a pretest, as well as the impact of the treatment on the critical analysis skills of PBTs through a posttest. The experimental group received inquiry-based learning with SPS-based Problem Analysis and Decision-Making Technique (PADT) (refer to Appendix 1), while the control group received conventional learning in the form of group discussions. Both groups were taught the same instructional material for a duration of 2 x 45 minutes per session. The integrated skills, which encompassed variable identification, data table formulation, graph formulation, variable association, data collection and processing, analysis, hypothesis formulation, and operational definition of variables (Asy'ari, Fitriani, et al., 2019), were incorporated into PADT in this study by employing scientific activities in the form of exploration worksheets.

Data Analysis

Critical analysis skills were assessed in a descriptive and statistical manner. The improvement in these skills was reflected by the mean scores obtained by the students for each indicator. The total score was analyzed using the following formula: n-gain = (posttest score - pretest score) / (maximum score - pretest score). Subsequently, the scores were divided into three categories: low (score < 0.30), moderate ($0.30 <$ score ≤ 0.70), and high (score > 0.70) (Hake, 1999). The responses of prospective teachers were analyzed using a critical analysis marking key, which assigned scores ranging from 1 to 4 (Fitriani et al., 2019b). The responses were then categorized based on Finken and Ennis's (1993) categories (Table 2).

Table 2

BPT critical analysis skills categories

Categories	Score
Not yet visible or still underdeveloped	1-2
Start developing or developing well	3-4

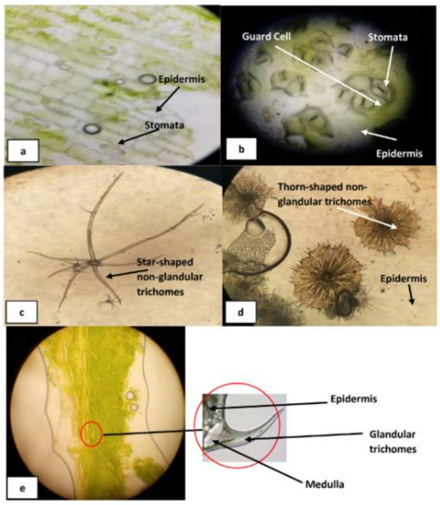
The impact of SPS-based PADT on PBTs' critical analysis skills was examined through the utilization of the analysis of covariance (ANCOVA) test, incorporating the pretest score as a covariate. Additionally, an independent-sample t-test was performed. Before conducting a parametric statistical test *(t-test*), the normality and homogeneity of the research data were assessed using the one-sample Kolmogorov-Smirnov and Levene's tests. The research data was determined to exhibit normal distribution with homogenous variance at $p > 0.05$ (alpha level). The statistical analysis was conducted using IBM SPSS 23, with a significance level set at 0.05.

Findings

PBTs' CA-skills descriptively improved according to n-gain score obtained both in the experimental and control group (Table 3). However, the category of PBTs' CA-skills in the experimental group obtained better improvement (high category) than the control group (moderate category). These findings indicate that the SPS-based PADT used as a learning resource and media can improve PBTs' CA-skills. Inquiry learning using SPS-based PADT facilitates PBTs in conducting experiments through identifying problems, formulating hypotheses, collecting and analyzing data, evaluating hypotheses, and generalizing results. In contrast to the control class which was taught using conventional learning (exploratory learning) without the support of SPS-based PADT, PBTs are asked to make summaries from various reading sources to identify images or solve problems given without conducting experiments/inquiry activities.

Figure 1

PBTs practicum results in the experimental group



Plant anatomy is a branch of biology that focuses on the microscopic structure of plants. It involves examining plant structures through incisions and observing them under a microscope. Including practicum activities in plant anatomy can greatly enhance learning by allowing students to interact with materials and observe phenomena firsthand. One example of such materials is the epidermis, which is a protective tissue that prevents water loss, mechanical damage, temperature fluctuations, and nutrient depletion in plants. Epidermal cells and their derivatives are found throughout the outer parts of the plant body and form the skin tissue system, which includes the epidermis itself, stomata, trichomes, lithosis, fan cells, silica cells, and other components. By carefully observing these materials, students can analyze the different types of epidermal derivatives present. In the experimental group, the students used a 4x10 magnification to examine the following samples during the practicum: Corn leaf stomata (*Zea mays*) (Figure 1a), Peanut leaf stomata (*Arachis hypogea*) (Figure 1b), hibiscus leaf trichomes (*Hibiscus tiliaceus*) (Figure 1c), Durian leaf trichome (*Durio zibethinus*) (Figure 1d), and Nettle leaf trichome (*Fleurya interrupta*) (Figure 1e).

Table 3

Critical analysis skills improvement

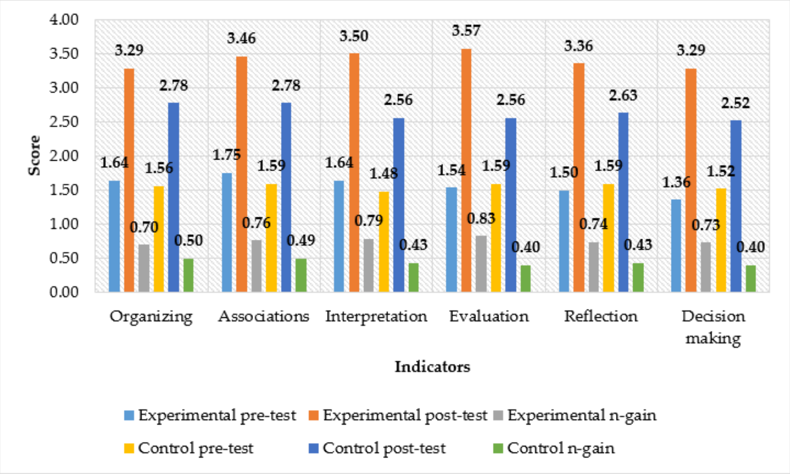
Group	Items	Indicators					
		O	A	I	E	R	DM
Experimental	Pretest	1.64	1.75	1.64	1.54	1.50	1.36
	Posttest	3.29	3.46	3.50	3.57	3.36	3.29
	n-gain	0.70	0.76	0.79	0.83	0.74	0.73
Control	Pretest	1.56	1.59	1.48	1.59	1.59	1.52
	Posttest	2.78	2.78	2.56	2.56	2.63	2.52
	n-gain	0.50	0.49	0.43	0.40	0.43	0.40

Note. O= Organizing, A= Associations, I= Interpretation, E= Evaluation, R= Reflection, DM= Decision making

The divergent treatments administered to the two groups yield disparate outcomes. The experimental group exhibited a superior enhancement of PBTs' CA skills, as evidenced by all the identified indicators in this study, when compared to the control group (Figure 2). These findings cannot be dissociated from the profound emphasis placed on PBTs in the experimental group, wherein they were instructed to procure practical resources to accomplish learning objectives aligned with the assigned topic, establish test protocols, interpret outcomes, engage in analytical activities, and make inferences.

Figure 2

The comparison of experimental and control group improvement



There was a notable disparity in the critical thinking abilities of the participants in the experimental group and the control group ($p < 0.05$; experimental mean = 3.4106; control mean = 2.6359). These results suggest that the SPS-based PADT, employed as instructional materials in the experimental group, substantially enhanced the participants' critical thinking abilities (Table 4).

Table 4

The comparison of SPS-based PADT impact on BPT critical analysis

Group	Item	N	Mean	Std. Dev	t	df	p
Experiment	Posttest	28	3.4106	.25850	12.014	53	.000
Control		27	2.6359	.21705			

The initial knowledge of prospective teachers can be assessed through pretest scores. To reinforce the assumption that the improvement in PBTs' CA-skills was due to the use of SPS-based instructions rather than other variables (pretest), an ANCOVA test was conducted, using the pretest score as a covariate (see Table 5). Although previous research has shown that students' prior knowledge plays a crucial role in the development of higher-order thinking skills (Martin et al., 2019; Piekny & Maehler, 2013), in the present study, students' prior knowledge (pretest) did not have a significant impact on PBTs' CA-skills ($p > .05$). These findings suggest that APDT based on SPS has a significant positive effect on enhancing PBTs' CA-skills.

Table 5

The initial knowledge impact on BPT critical analysis

Source	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	8.462[a]	2	4.231	78.113	.000
Intercept	6.519	1	6.519	120.364	.000
Pretest	.213	1	.213	3.925	.053
Group	8.139	1	8.139	150.268	.000
Error	2.816	52	.054		
Total	516.331	55			
Corrected Total	11.278	54			

Discussion

This study investigates the impact of utilizing SPS-based PADT on the CA skills of PBTs. The results indicate that the experimental group, instructed with SPS-based PADT, exhibited a notable improvement in CA skills compared to the control group. Textbooks have a vital role in science education, especially in the field of biology (Hultén, 2016). They can enhance learning outcomes and facilitate effective communication of learning models and strategies (Fitriani et al., 2019a). However, biology materials, which encompass factual, conceptual, and procedural knowledge, necessitate a structured presentation rooted in scientific methods (Rofieq et al., 2021). In this context, SPS functions as the basis for constructing scientific knowledge (Asy'ari et al., 2019; Nur, 2011) and is crucial for delivering biology teaching materials without introducing bias into the learning process (Dancy et al., 2016).

The Science Process Skills (SPS)-based Problem Analysis and Design Tool (PADT) was developed to align with the key features of science as a body of knowledge, the exploration of nature, critical thinking abilities, and the interplay between nature, technology, and society. These features are in line with the fundamental principles of science as a process (Molefe & Stears, 2014), which are typically implemented through the inquiry-based learning model (Rönnebeck et al., 2016), particularly in the context of science education (Pedaste et al., 2015). Inquiry-based learning places emphasis on formulating scientific inquiries, developing evidence-based conclusions, and engaging in discussions about scientific concepts (Furtak et al., 2012). In this study, inquiry-based learning is implemented by guiding Problem-Based Tasks (PBTs) in (1) formulating experimental procedures, (2) analyzing and evaluating experimental results, and (3) discussing and communicating the findings (Figure 1). These learning activities promote the active involvement of PBTs in their learning process, which has been found to effectively enhance the component of critical thinking and analytical skills when using the SPS-based PADT. The positive impact of inquiry-based learning on the science learning outcomes of PBTs has been extensively demonstrated. The findings indicate that 77% of prospective science teachers provided positive feedback and believed that inquiry-based learning could improve understanding and academic skills (McLoughlin et al., 2014). In support of the results of this study, Sotiriou et al. (2020) emphasized that the experience of inquiry-based learning can contribute to a deeper understanding of scientific concepts.

Based on the perspective of meaningful learning, learners should be provided with continuous opportunities to develop scientific knowledge and skills (Mtshali & Msimango, 2023; Mystakidis, 2021; Wirzal, Nordin, et al., 2022) through inquiry-based learning. The process of inquiry-based learning not only enables students to generate scientific knowledge and develop an understanding of concepts related to the learning materials (Muhali et al., 2021), but also assists students in engaging in scientific practices (Alhendal et al., 2016) to cultivate critical thinking and analytical (CA) skills through activities such as observation, questioning, evaluation and management of information, data analysis, interpretation, explanation, and cognitive regulation (Asy'ari et al., 2019; Muhali et al., 2019). The enhancement of PBTs' CA skills in inquiry-based learning with the SPS-based PADT is further supported by practical activities that promote scientific behavior, application of prior knowledge, and construction of new knowledge. This is evidenced by the substantial increase in the n-gain score of PBTs' CA skills in the experimental group, which falls within the high category (n-gain > 0.70) for each indicator (Figure 3). In contrast, the CA skills of PBTs in the control group also exhibited improvement, but it was in the moderate category (0.30 < n-gain < 0.70). We need some indication as to why BOTH groups benefited. Although research findings suggest that hands-on activities may not always be effective in improving students' conceptual understanding (Pfaff & Weinberg, 2017; Septaria & Rismayanti, 2022), there are still many students who lack confidence, and the implementation of inquiry-based learning can assist them in achieving positive learning outcomes (Ebrahim, 2012). Moreover, the results of other empirical studies have also demonstrated similar findings to this study, where learning that incorporates hands-on activities increases students' scientific behavior (Kilic et al., 2011; Prokop & Fančovičová, 2017), performance, motivation, and participation in science learning (Erickson et al., 2020; McDonald et al., 2017). However, it is worth mentioning that these studies were conducted with primary and middle school students and did not explicitly focus on PBTs' CA skills, as was done in this study.

Inquiry-based learning using SPS-based PADT demonstrated a significant impact ($p < 0.05$) on the critical thinking (CA) skills of prospective biology teachers (PBTs) (Table 5). The experimental group exhibited a higher mean score for CA skills (mean = 3.4106) compared to the control group (mean = 2.6359). The results indicated that the CA skills of the experimental group were categorized as either starting to develop or developing well (score = 3-4), while those of the control group were categorized as not yet visible or still underdeveloped (score = 1-2). The effectiveness of SPS-based PADT was further supported by the ANCOVA test, where the PBTs' pretest scores were used as a covariate (Table 6). The results revealed that the PBTs' prior knowledge (pretest) did not have a significant effect ($p > 0.05$) on their CA skills. These findings suggest that SPS-based PADT in the experimental group was the primary factor contributing to the improvement of PBTs' CA skills. The integration of SPS features in experimental activities, thinking skills, and conceptual contextualization within SPS-based PADT, along with a conducive learning environment, enhanced PBTs' motivation to learn. Consequently, this had a positive impact on the improvement of their CA skills. Our findings align with the research of Ekmekci and Gulacar (2015), who found that learning through experimental activities resulted in increased student engagement, motivation, collaboration, and communication. Furthermore, other studies evaluating the impact of inquiry-based learning (Prayogi et al., 2018), collaborative learning, and problem-based learning (Karantzas et al., 2013) share theoretical features relevant to the SPS-based PADT employed in our study. Our study contributes to the body of knowledge by demonstrating a positive impact of the implemented treatment on the development of critical thinking skills and CA skills among prospective teachers.

On the other hand, previous studies have found that inquiry-based learning is not more effective in improving critical thinking dispositions (Arsal, 2017) and the construction of scientific explanations (Jantrasee, 2022) compared to learning in the control group. It has also been negatively correlated with learning outcomes (Cairns & Areepattamannil, 2019). Students taught using intensive or frequent investigation-based learning tend to have a negative impact on science learning outcomes (Teig et al., 2018). These results contradict another study that demonstrated a significant impact of inquiry-based learning on PBTs' CA-skills ($p< 0.05$) and showed better learning outcomes compared to conventional learning in the control group. These different results may be attributed to differences in the context and methodologies used (Kwan & Wong, 2015; Qing et al., 2010). In this study, IBL was supported by the use of SPS-based PADT to enhance PBTs' CA-skills. Consistent with the findings of this study, Sari et al. (2020) discovered that the IBL environment has a positive effect on the development of scientific process skills and STEM awareness. SPS in this study assists PBTs in organizing the process of investigation and knowledge construction in science learning (Kruit et al., 2018). Furthermore, PBTs' skills in interpreting, analyzing, evaluating (Asy'ari et al., 2019), and learning autonomy (Constantinou et al., 2018; Kaçar & Balim, 2021; Yıldız-Feyzioğlu & Demirci, 2021) can be improved.

Conclusion and Implications

The findings of this study suggest that inquiry-based learning (IBL) with Self-Regulated Learning (SRL) Problem Analysis and Decision Making (PADT)has a significant impact on the critical thinking (CT) skills of prospective teachers. The experimental group demonstrated a greater improvement in CT skills compared to the control group. The initial knowledge of the prospective teachers, which was found to be homogeneous, did not significantly affect the development of CT skills. This strengthens the conclusion that SRL-based PADT effectively enhances the CT skills of prospective teachers. The results indicate that SRL-based PADT is a valuable teaching tool for improving CT skills among prospective teachers. To achieve the desired learning outcomes in CT skills, educators should carefully consider and prepare for the integration of higher-order thinking skills (HOTS) and learning models that encourage active learner participation. While this study focused solely on CT skills, it is worth noting that these skills are closely linked to other thinking skills such as problem-solving, metacognition, and critical thinking. Therefore, future studies should explore the impact of learning models such as problem-based learning, cooperative learning, and cognitive conflict learning, which are believed to have the potential to enhance students' thinking skills. Furthermore, it is important to investigate the impact of SRL-based PADT on prospective teachers' CT skills using a wider range of teaching materials beyond those used in this study.

References

Aktamış, H., & Yenice, N. (2010). Determination of the science process skills and critical thinking skill levels. *Procedia - Social and Behavioral Sciences*, *2*(2), 3282–3288. https://doi.org/10.1016/j.sbspro.2010.03.502

Alhendal, D., Marshman, M., & Grootenboer, P. (2016). Kuwaiti Science Teachers' Beliefs and Intentions Regarding the Use of Inquiry-Based Instruction. *International Journal of Science and Mathematics Education*, *14*(8), 1455–1473. https://doi.org/10.1007/s10763-015-9671-0

Alsaleh, N. J. (2020). Teaching Critical Thinking Skills: Literature Review. *The Turkish Online Journal of Educational Technology*, *19*(1), 21–39.

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* (Complete ed). Longman.

Arsal, Z. (2017). The impact of inquiry-based learning on the critical thinking dispositions of pre-service science teachers. *International Journal of Science Education*, *39*(10), 1326–1338. https://doi.org/10.1080/09500693.2017.1329564

Arum, R., Cho, E., Kim, J., & Roksa, J. (2012). *Documenting uncertain times: Post-graduate transitions of the "Academically adrift" cohort* (TD/TNC 107.987; p. 23). Social Science Research Council. http://www.ssrc.org/workspace/images/crm/new_publication_3/%7Bfcfb0e86-b346-e111-b2a8-001cc477ec84%7D.pdf

Asy'ari, M., Fitriani, H., Zubaidah, S., & Mahanal, S. (2019). The Science Process Skills of Prospective Biology Teachers in Plant Cell Material Based on Gender. *International Journal of Emerging Technologies in Learning (iJET)*, *14*(19), 168. https://doi.org/10.3991/ijet.v14i19.11208

Asy'ari, M., Ikhsan, M., & Muhali, M. (2019). The Effectiveness of Inquiry Learning Model in Improving Prospective Teachers' Metacognition Knowledge and Metacognition Awareness. *International Journal of Instruction*, *12*(2), Article 2. https://doi.org/10.29333/iji.2019.12229a

Barsoum, M. J., Sellers, P. J., Malcolm Campbell, A., Heyer, L. J., & Paradise, C. J. (2013). Implementing recommendations for introductory biology by writing a new textbook. *CBE Life Sciences Education*, *12*(1), 106–116. Scopus. https://doi.org/10.1187/cbe.12-06-0086

Brookhart, S. M. (2010). *How to assess higher-order thinking skills in your classroom*. ASCD.

Bulent, A. (2015). The investigation of science process skills of science teachers in terms of some variables. *Educational Research and Reviews*, *10*(5), 582–594. https://doi.org/10.5897/ERR2015.2097

Caesar, M. I. M., Jawawi, R., Matzin, R., Shahrill, M., Jaidin, J. H., & Mundia, L. (2016). The Benefits of Adopting a Problem-Based Learning Approach on Students' Learning Developments in Secondary Geography Lessons. *International Education Studies*, *9*(2), 51. https://doi.org/10.5539/ies.v9n2p51

Cairns, D., & Areepattamannil, S. (2019). Exploring the Relations of Inquiry-Based Teaching to Science Achievement and Dispositions in 54 Countries. *Research in Science Education*, *49*(1), 1–23. https://doi.org/10.1007/s11165-017-9639-x

Christian, K. B., Kelly, A. M., & Bugallo, M. F. (2021). NGSS-based teacher professional development to implement engineering practices in STEM instruction. *International Journal of STEM Education*, *8*(1). Scopus. https://doi.org/10.1186/s40594-021-00284-1

Constantinou, C. P., Tsivitanidou, O. E., & Rybska, E. (2018). What Is Inquiry-Based Science Teaching and Learning? In O. E. Tsivitanidou, P. Gray, E. Rybska, L. Louca, & C. P. Constantinou (Eds.), *Professional Development for Inquiry-Based Science Teaching and Learning* (Vol. 5, pp. 1–23). Springer International Publishing. https://doi.org/10.1007/978-3-319-91406-0_1

Dancy, M., Henderson, C., & Turpen, C. (2016). How faculty learn about and implement research-based instructional strategies: The case of Peer Instruction. *Physical Review Physics Education Research*, *12*(1), 010110. https://doi.org/10.1103/PhysRevPhysEducRes.12.010110

Davenport Huyer, L., Callaghan, N. I., Dicks, S., Scherer, E., Shukalyuk, A. I., Jou, M., & Kilkenny, D. M. (2020). Enhancing senior high school student engagement and academic performance using an inclusive and scalable inquiry-based program. *Npj Science of Learning*, *5*(1). Scopus. https://doi.org/10.1038/s41539-020-00076-2

Davies, M. (2013). Critical thinking and the disciplines reconsidered. *Higher Education Research & Development*, *32*(4), 529–544. https://doi.org/10.1080/07294360.2012.697878

Davies, M., & Barnett, R. (Eds.). (2015). *The Palgrave handbook of critical thinking in higher education*. Palgrave Macmillan.

Durmaz, H., & Mutlu, S. (2017). The effect of an instructional intervention on elementary students' science process skills. *The Journal of Educational Research*, *110*(4), 433–445. https://doi.org/10.1080/00220671.2015.1118003

Ebrahim, A. (2012). The effect of cooperative learning strategies on elementary students' science achievement and social skills in Kuwait. *International Journal of Science and Mathematics Education*, *10*(2), 293–314. https://doi.org/10.1007/s10763-011-9293-0

Eggen, P. D., & Kauchak, D. P. (2012). *Strategies and models for teachers: Teaching content and thinking skills* (6th ed). Pearson.

Ekmekci, A., & Gulacar, O. (2015). A Case Study for Comparing the Effectiveness of a Computer Simulation and a Hands-On Activity on Learning Electric Circuits. *EURASIA Journal of Mathematics, Science and Technology Education*, *11*(4). https://doi.org/10.12973/eurasia.2015.1438a

Ennis, R. H. (2018). Critical Thinking Across the Curriculum: A Vision. *Topoi*, *37*(1), 165–184. https://doi.org/10.1007/s11245-016-9401-4

Erickson, M., Marks, D., & Karcher, E. (2020). Characterizing student engagement with hands-on, problem-based, and lecture activities in an introductory college course. *Teaching & Learning Inquiry*, *8*(1), 138–153. https://doi.org/10.20343/teachlearninqu.8.1.10

Facione, P. A. (2020). *Critical Thinking: What It Is and Why It Counts*. Measured Reasons LCC. https://www.insightassessment.com/wp-content/uploads/ia/pdf/whatwhy.pdf

Finken, M., & Ennis, R. H. (1993). *Illinois Critical Thinking Essay Test* [Illinois Critical Thinking Project].

Fisher, A. (2011). *Critical thinking: An introduction* (2nd ed). Cambridge University Press.

Fitriani, H., Asy'ari, M., Zubaidah, S., & Mahanal, S. (2019a). *Pengembangan buku ajar anatomi dan perkembangan tumbuhan terintegrasi kps untuk melatih kemampuan analisis kritis mahasiswa [Development of plants anatomy and development textbook based on science process skills to facilitate students' critical analysis ability]* (Research Report 3/E/KPT/2018). Universitas Pendidikan Mandalika.

Fitriani, H., Asy'ari, M., Zubaidah, S., & Susriyati, M. (2019b). Exploring the Prospective Teachers' Critical Thinking and Critical Analysis Skills. *Jurnal Pendidikan IPA Indonesia*, *8*(3). https://doi.org/10.15294/jpii.v8i3.19434

Flores, K. L., Matkin, G. S., Burbach, M. E., Quinn, C. E., & Harding, H. (2012). Deficient Critical Thinking Skills among College Graduates: Implications for leadership. *Educational Philosophy and Theory*, *44*(2), 212–230. https://doi.org/10.1111/j.1469-5812.2010.00672.x

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education* (8th ed). McGraw-Hill Humanities/Social Sciences/Languages.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and Quasi-Experimental Studies of Inquiry-Based Science Teaching: A Meta-Analysis. *Review of Educational Research*, *82*(3), 300–329. https://doi.org/10.3102/0034654312457206

Guo, L., & Wang, J. (2021). Relationships between teacher autonomy, collaboration, and critical thinking focused instruction: A cross-national study. *International Journal of Educational Research*, *106*, 101730. https://doi.org/10.1016/j.ijer.2020.101730

Haerazi, H., Dehghani, S., Rachmawati, U., & Irwansyah, D. (2021). The C-BIM Model in Improving Reading, Writing, and Critical Thinking Skills: Outcome and Perception. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *5*(2), 152–167. https://doi.org/10.36312/esaintika.v5i2.503

Hake, R. R. (1999). *Analyzing Change/Gain Scores**. 4.

Halpern, D. F. (2014). *Thought and Knowledge: An Introduction to Critical Thinking*. Psycology Press. https://www.routledge.com/Thought-and-Knowledge-An-Introduction-to-Critical-Thinking/Halpern/p/book/9781848726291

Hamouda, A. M. S., & Tarlochan, F. (2015). Engaging Engineering Students in Active Learning and Critical Thinking through Class Debates. *Procedia - Social and Behavioral Sciences*, *191*, 990–995. https://doi.org/10.1016/j.sbspro.2015.04.379

Haug, B. S., & Mork, S. M. (2021). Taking 21st century skills from vision to classroom: What teachers highlight as supportive professional development in the light of new demands from educational reforms. *Teaching and Teacher Education*, *100*, 103286. https://doi.org/10.1016/j.tate.2021.103286

Heijltjes, A., van Gog, T., Leppink, J., & Paas, F. (2015). Unraveling the effects of critical thinking instructions, practice, and self-explanation on students' reasoning performance. *Instructional Science*, *43*(4), 487–506. https://doi.org/10.1007/s11251-015-9347-8

Heritage, B., Roberts, L. D., & Gasson, N. (2016). Psychological Literacy Weakly Differentiates Students by Discipline and Year of Enrolment. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00162

Hidayatulloh, R., Suyono, S., & Azizah, U. (2020). Development of STEM-Based Chemistry Textbooks to Improve Students' Problem Solving Skills. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *4*(3), Article 3. https://doi.org/10.36312/e-saintika.v4i3.306

Hincapié Parra, D. A., Ramos Monobe, A., & Chrino-Barceló, V. (2018). Problem based learning as an active learning strategy and its impact on academic performance and critical thinking of medical students. *Revista Complutense de Educacion*, *29*(3), 665–681. Scopus. https://doi.org/10.5209/RCED.53581

Holmes, J., Guy, J., Kievit, R. A., Bryant, A., Mareva, S., Calm Team, & Gathercole, S. E. (2021). Cognitive dimensions of learning in children with problems in attention, learning, and memory. *Journal of Educational Psychology*, *113*(7), 1454–1480. https://doi.org/10.1037/edu0000644

Hultén, M. (2016). Scientists, teachers and the 'scientific' textbook: Interprofessional relations and the modernisation of elementary science textbooks in nineteenth-century Sweden. *History of Education*, *45*(2), 143–168. https://doi.org/10.1080/0046760X.2015.1060542

Karantzas, G. C., Avery, M. R., Macfarlane, S., Mussap, A., Tooley, G., Hazelwood, Z., & Fitness, J. (2013). Enhancing critical analysis and problem-solving skills in undergraduate psychology: An evaluation of a collaborative learning and problem-based learning approach. *Australian Journal of Psychology*, *65*(1), 38–45. https://doi.org/10.1111/ajpy.12009

Kilic, D. S., Emsen, P., & Soran, H. (2011). Behavioral Intention Towards Laboratory Applications in Science Teaching. *Procedia - Social and Behavioral Sciences*, *28*, 416–420. https://doi.org/10.1016/j.sbspro.2011.11.079

Klimova, B. F. (2013). Developing Thinking Skills in the Course of Academic Writing. *Procedia - Social and Behavioral Sciences*, *93*, 508–511. https://doi.org/10.1016/j.sbspro.2013.09.229

Knight, B. A. (2015). Teachers' use of textbooks in the digital age. *Cogent Education*, *2*(1), 1015812. https://doi.org/10.1080/2331186X.2015.1015812

Knight, B. A., & Horsley, M. (2013). The ecology of change and continuity in the use of textbooks in higher education. *TEXT*, *23*, 1–13. https://doi.org/10.52086/001c.28291

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Assessing students' ability in performing scientific inquiry: Instruments for measuring science skills in primary education. *Research in Science and Technological Education*, *36*(4), 413–439. Scopus. https://doi.org/10.1080/02635143.2017.1421530

Kwan, Y. W., & Wong, A. F. L. (2015). Effects of the constructivist learning environment on students' critical thinking ability: Cognitive and motivational variables as mediators. *International Journal of Educational Research*, *70*, 68–79. https://doi.org/10.1016/j.ijer.2015.02.006

Lazonder, A. W., & Egberink, A. (2014). Children's acquisition and use of the control-of-variables strategy: Effects of explicit and implicit instructional guidance. *Instructional Science*, *42*(2), 291–304. https://doi.org/10.1007/s11251-013-9284-3

Lazonder, A. W., & Harmsen, R. (2016). Meta-Analysis of Inquiry-Based Learning: Effects of Guidance. *Review of Educational Research*, *86*(3), 681–718. https://doi.org/10.3102/0034654315627366

Lee, H.-Y. (2014). Inquiry-based Teaching in Second and Foreign Language Pedagogy. *Journal of Language Teaching and Research*, *5*(6), 1236–1244. https://doi.org/10.4304/jltr.5.6.1236-1244

Madsen, A., McKagan, S. B., Martinuk, M. S., Bell, A., & Sayre, E. C. (2016). Research-based assessment affordances and constraints: Perceptions of physics faculty. *Physical Review Physics Education Research*, *12*(1), 010115. https://doi.org/10.1103/PhysRevPhysEducRes.12.010115

Marth, M., & Bogner, F. X. (2017). Does the issue of bionics within a student-centered module generate long-term knowledge? *Studies in Educational Evaluation*, *55*, 117–124. https://doi.org/10.1016/j.stueduc.2017.09.001

Martin, N. D., Dornfeld Tissenbaum, C., Gnesdilow, D., & Puntambekar, S. (2019). Fading distributed scaffolds: The importance of complementarity between teacher and material scaffolds. *Instructional Science*, *47*(1), 69–98. https://doi.org/10.1007/s11251-018-9474-0

McDonald, F., Reynolds, J., Bixley, A., & Spronken-Smith, R. (2017). Changes in approaches to learning over three years of university undergraduate study. *Teaching & Learning Inquiry*, *5*(2), 65. https://doi.org/10.20343/teachlearninqu.5.2.6

McLaughlin, J. E., Roth, M. T., Glatt, D. M., Gharkholonarehe, N., Davidson, C. A., Griffin, L. M., Esserman, D. A., & Mumper, R. J. (2014). The Flipped Classroom: A Course Redesign to Foster Learning and Engagement in a Health Professions School. *Academic Medicine*, *89*(2), 236–243. https://doi.org/10.1097/ACM.0000000000000086

McLoughlin, E., Finlayson, O., & Brady, S. (2014). Learners as initiators through inquiry based science education – Experiences from the European project ESTABLISH. *All Ireland Journal of Higher Education*, *6*(3), Article 3. https://ojs.aishe.org/index.php/aishe-j/article/view/182

Mena, N. P. (2019). Teaching violence, drug trafficking and armed conflict in colombian schools: Are history textbooks deficient? *Issues in Educational Research*, *29*(3), 899–922. Scopus.

Molefe, L., & Stears, M. (2014). Rhetoric and Reality: Science Teacher Educators' Views and Practice Regarding Science Process Skills. *African Journal of Research in Mathematics, Science and Technology Education*, *18*(3), 219–230. https://doi.org/10.1080/10288457.2014.942961

Morris, S., Cranney, J., Jeong, J. M., & Mellish, L. (2013). Developing psychological literacy: Student perceptions of graduate attributes. *Australian Journal of Psychology*, *65*(1), 54–62. https://doi.org/10.1111/ajpy.12010

Mtshali, T. I., & Msimango, S. M. (2023). Factors Influencing Construction Technology Teachers' Ability to Conduct Simulations Effectively. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *7*(1), Article 1. https://doi.org/10.36312/esaintika.v7i1.1079

Muhali, M., Prahani, B. K., Mubarok, H., Kurnia, N., & Asy'ari, M. (2021). The Impact of Guided-Discovery-Learning Model on Students' Conceptual Understanding and Critical Thinking Skills. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *5*(3), 227–240. https://doi.org/10.36312/esaintika.v5i3.581

Muhali, M., Yuanita, L., & Ibrahim, M. (2019). The Validity and Effectiveness of the Reflective-Metacognitive Learning Model to Improve Students' Metacognition Ability in Indonesia. *Malaysian Journal of Learning and Instruction*, *16*(2), 33–74. https://doi.org/10.32890/mjli2019.16.2.2

Mystakidis, S. (2021). Deep Meaningful Learning. *Encyclopedia*, *1*(3), 988–997. https://doi.org/10.3390/encyclopedia1030075

Mystakidis, S., Berki, E., & Valtanen, J. (2019). The Patras Blended Strategy Model for Deep and Meaningful Learning in Quality Life-Long Distance Education. *Electronic Journal of E-Learning*, *17*(2). https://doi.org/10.34190/JEL.17.2.01

Nur, M. (2011). *Modul Keterampilan-keterampilan Proses dan Hakikat Sains*. PSMS Unesa.

Pahrudin, A., Misbah, M., Alisia, G., Saregar, A., Asyhari, A., Anugrah, A., & Endah, N. (2021). The Effectiveness of Science, Technology, Engineering, and Mathematics-Inquiry Learning for 15-16 Years Old Students Based on K-13 Indonesian Curriculum: The Impact on the Critical Thinking Skills. *European Journal of Educational Research*, *10*(2), 681–692. https://doi.org/10.12973/eu-jer.10.2.681

Pantò, E., & Comas-Quinn, A. (2013). The Challenge of Open Education. *Journal of E-Learning and Knowledge Society*, *Vol 9*, No 1 (2013): Journal of eLearning and Knowledge Society: Focus on: Open Educational Resources (OER) and Open Educational Practices (OEP). https://doi.org/10.20368/1971-8829/798

Pascarella, E. T., Blaich, C., Martin, G. L., & Hanson, J. M. (2011). How Robust Are the Findings of *Academically Adrift? Change: The Magazine of Higher Learning*, *43*(3), 20–24. https://doi.org/10.1080/00091383.2011.568898

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Pfaff, T. J., & Weinberg, A. (2017). Do Hands-on Activities Increase Student Understanding?: A Case Study. *Journal of Statistics Education*, *17*(3), 7. https://doi.org/10.1080/10691898.2009.11889536

Piekny, J., & Maehler, C. (2013). Scientific reasoning in early and middle childhood: The development of domain-general evidence evaluation, experimentation, and hypothesis generation skills. *British Journal of Developmental Psychology*, *31*(2), 153–179. https://doi.org/10.1111/j.2044-835X.2012.02082.x

Prayogi, S., Yuanita, L., & Wasis. (2018). Critical Inquiry Based Learning: A Model of Learning to Promote Critical Thinking Among Prospective Teachers of Physic. *Journal of Turkish Science Education*, *15*(1), Article 1.

Prokop, P., & Fančovičová, J. (2017). The effect of hands-on activities on children's knowledge and disgust for animals. *Journal of Biological Education*, *51*(3), 305–314. https://doi.org/10.1080/00219266.2016.1217910

Qing, Z., Jing, G., & Yan, W. (2010). Promoting preservice teachers' critical thinking skills by inquiry-based chemical experiment. *Procedia - Social and Behavioral Sciences*, *2*(2), 4597–4603. https://doi.org/10.1016/j.sbspro.2010.03.737

Rofieq, A., Hindun, I., Shultonnah, L., & Miharja, F. J. (2021). Developing textbook based on scientific approach, critical thinking, and science process skills. *Journal of Physics: Conference Series*, *1839*(1), 012030. https://doi.org/10.1088/1742-6596/1839/1/012030

Rönnebeck, S., Bernholt, S., & Ropohl, M. (2016). Searching for a common ground – A literature review of empirical research on scientific inquiry activities. *Studies in Science Education*, *52*(2), 161–197. https://doi.org/10.1080/03057267.2016.1206351

Ruggiero, V. R. (2015). *The art of thinking: A guide to critical and creative thought* (ELEVENTH EDITION). Pearson.

Rusmansyah, R., Yuanita, L., Ibrahim, M., Isnawati, I., & Prahani, B. K. (2019). Innovative chemistry learning model: Improving the critical thinking skill and self-efficacy of pre-service chemistry teachers. *Journal of Technology and Science Education*, *9*(1), 59. https://doi.org/10.3926/jotse.555

Sambudi, N. S., Jusoh, N., Sapiaa, N. A. H., & Ahmad, S. I. (2023). Integrated Project in Separation Process Class as Innovative Tool to Improve Students' Online Learning Experience. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *7*(1), 18–29. https://doi.org/10.36312/esaintika.v7i1.1042

Schallert, S., Lavicza, Z., & Vandervieren, E. (2020). Merging flipped classroom approaches with the 5E inquiry model: A design heuristic. *International Journal of Mathematical Education in Science and Technology*, 1–18. https://doi.org/10.1080/0020739X.2020.1831092

Schmid, S., & Bogner, F. X. (2015). Effects of Students' Effort Scores in a Structured Inquiry Unit on Long-Term Recall Abilities of Content Knowledge. *Education Research International*, *2015*, 1–11. https://doi.org/10.1155/2015/826734

Septaria, K., & Rismayanti, R. (2022). The Effect of Scientific Approach on Junior High School Students' Scientific Creativity and Cognitive Learning Outcomes. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *6*(3), Article 3. https://doi.org/10.36312/esaintika.v6i3.955

Sormunen, K., & Serdar, M. (2014). Advanced Science Students' Understandings on Nature of Science in Finland. *European Journal of Educational Research*, *3*(4), 167–176. https://doi.org/10.12973/eu-jer.3.4.167

Sotiriadou, P., & Hill, B. (2015). Using scaffolding to promote sport management graduates' critical thinking. *Annals of Leisure Research*, *18*(1), 105–122. https://doi.org/10.1080/11745398.2014.925406

Sotiriou, S. A., Lazoudis, A., & Bogner, F. X. (2020). Inquiry-based learning and E-learning: How to serve high and low achievers. *Smart Learning Environments*, *7*(1), 29. https://doi.org/10.1186/s40561-020-00130-x

Spector, J. M., & Ma, S. (2019). Inquiry and critical thinking skills for the next generation: From artificial intelligence back to human intelligence. *Smart Learning Environments*, *6*(1), 8, s40561-019-0088-z. https://doi.org/10.1186/s40561-019-0088-z

Teig, N., Scherer, R., & Nilsen, T. (2018). More isn't always better: The curvilinear relationship between inquiry-based teaching and student achievement in science. *Learning and Instruction*, *56*, 20–29. https://doi.org/10.1016/j.learninstruc.2018.02.006

Thomas, T. A. (2011). Developing First Year Students' Critical Thinking Skills. *Asian Social Science*, *7*(4), p26. https://doi.org/10.5539/ass.v7n4p26

Tiruneh, D. T., Verburgh, A., & Elen, J. (2014). Effectiveness of Critical Thinking Instruction in Higher Education: A Systematic Review of Intervention Studies. *Higher Education Studies*, *4*(1), p1. https://doi.org/10.5539/hes.v4n1p1

Wale, B. D., & Bishaw, K. S. (2020). Effects of using inquiry-based learning on EFL students' critical thinking skills. *Asian-Pacific Journal of Second and Foreign Language Education*, *5*(1), 9. https://doi.org/10.1186/s40862-020-00090-2

Wirzal, M. D. H., Halim, N. S. A., Md Nordin, N. A. H., & Bustam, M. A. (2022). Metacognition in Science Learning: Bibliometric Analysis of Last Two Decades. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *6*(1), 43–60. https://doi.org/10.36312/esaintika.v6i1.665

Wirzal, M. D. H., Nordin, N. A. H. M., Bustam, M. A., & Joselevich, M. (2022). Bibliometric Analysis of Research on Scientific Literacy between 2018 and 2022: Science Education Subject. *International Journal of Essential Competencies in Education*, *1*(2), Article 2. https://doi.org/10.36312/ijece.v1i2.1070

Woolfolk Hoy, A., Davis, H. A., & Anderman, E. M. (2013). Theories of Learning and Teaching in TIP. *Theory Into Practice*, *52*(sup1), 9–21. https://doi.org/10.1080/00405841.2013.795437

Appendix 1

Sample of Lesson Plan Procedures
Stage 1: Introduction (10 minutes)
• Begin by discussing the importance of plants in our daily lives and their role in ecosystems. For example, presenting a phenomenon or problem like: “Imagine a world where our understanding of plant tissues and their derivatives holds the key to addressing critical global challenges. As prospective biology teachers, you are tasked with exploring the intricate world of plant anatomy and development, focusing on how plants produce tissues that serve as the building blocks for an array of essential products. From textiles like cotton to natural rubber, timber for construction, and even life-saving pharmaceuticals derived from plants, these tissues have a profound impact on our lives and the environment. But how do plants manufacture these valuable materials at the microscopic level, and what ecological and economic implications do these processes carry? To prepare you for your role in teaching the next generation, let's embark on an inquiry-based journey to understand how plant tissues give rise to these vital derivatives and the complex web of interactions that make it all possible.” • Share the lesson objectives with the students. • Ask students what they already know about plant tissues and derivatives, and record their responses on the board.
Stage 2: Engage (15 minutes)
• Show images of different plant tissues on the projector. • Ask students to make observations and discuss what they see. • Prompt questions like: "What differences do you notice in the tissues?" and "Why do you think plants have different types of tissues?"
Stage 3: Explore (30 minutes)
• Distribute microscopes and prepared slides of plant tissues. • In small groups, students will examine the plant tissue slides. • Encourage them to record their observations and make sketches in their lab notebooks. • Students should try to identify the types of tissues they see (e.g., epidermal tissue, xylem, phloem, etc.)
Stage 4: Explain (20 minutes)
• Have a class discussion about the different types of plant tissues observed. • Use the diagrams provided in handouts to explain the functions and roles of various plant tissues. • Discuss how these tissues contribute to plant growth and development.
Stage 5: Elaborate (15 minutes)
• Show examples of plant derivatives (e.g., zea mays, Arachis hypogea, Hibiscus tiliaceus). • Discuss how these derivatives are obtained from different plant tissues. • Ask students to think about the ecological significance of these derivatives. • Encourage students to share any personal experiences or knowledge related to plant derivatives.
Stage 6: Evaluate (10 minutes)
• Assign a homework assignment: Have students research and write a short essay on the importance of plant tissues and derivatives in modern society. • Review the main concepts discussed in the lesson. • Answer any questions or concerns the students may have.
Stage 7: Reflection (5 minutes)
• Summarize the key takeaways from the lesson. • Emphasize the relevance of plant tissues and derivatives in biology education. • Encourage students to explore more about plants and their applications in their future teaching careers.