Research Article

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# Exploring the implementation of stepwise inquiry-based learning in higher education

https://doi.org/10.1515/cti-2023-0081
Received December 31, 2023; accepted August 12, 2024; published online August 28, 2024

**Abstract:** The study aims to explore the implementation of stepwise inquiry in chemistry education. The levels of inquiry used range from structured inquiry (level 1) to guided inquiry (level 2). The research design involved methods of analyzing the implementation of inquiry levels, assessing the ability to answer questions, engage in critical thinking, and gather student responses. The research sample consisted of 73 students studying biochemistry. A total of 14 groups, each containing 5–6 members, were involved in this research. The research results show that six groups (SG) successfully followed the investigation process at the inquiry steps, while eight groups were unsuccessful (UG). The average scores of the sub-skills collaboration, communication, data collection, use of equipment, and implementation of experimental design were the highest compared to other subskills. The stages of interpreting problems, observation, experimental design, formulating hypotheses, data analysis, and developing conclusions are still in progress and are classified as low. The SG group had an average N-Gain critical thinking score higher than the UG group ($p < 0.05$). The analysis of the ability to answer questions and think critically shows that the category of developing hypotheses and analyzing arguments had the lowest ability to respond compared to other indicators.

**Keywords:** critical thinking; guided inquiry; biochemistry learning; structured inquiry

## 1 Introduction

The learning process after the pandemic presents different challenges from previous learning experiences. Online learning conditions significantly influence students' learning (Azubuike et al., 2021). Instructions that are one-way in nature in online learning can lead to cognitive challenges for students, potentially resulting in conceptual errors and suboptimal learning outcomes. Achieving meaningful learning tends to be more difficult (Bacher-Hicks et al. 2021; Rai et al. 2021).

To address this, cognitive, social, and process elements in learning are now being implemented, especially in universities. Innovative methods are being used in every lecture to help students acquire the long-term skills they need (Willey et al., 2020). The inquiry approach is being implemented to train students' thinking skills and reintroduce cognitive, social, and process elements that may not have been optimally presented in online learning (Lau et al., 2021).

Constructivist theory forms the basis for implementing inquiry-based learning, suggesting that individuals actively build knowledge from what they perceive through their senses, using existing knowledge (Johnstone, 2006). According to this theory, every individual constructs their own understanding, and the ability to connect new knowledge with previous understanding demonstrates effective learning. Constructivism is particularly relevant to science education, especially in chemistry (Gabel, 1999).

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Learning chemistry involves three levels of thinking: macroscopic, sub-microscopic, and symbolic collectively referred to as the Johnstone Triangle (Johnstone, 2006; Talanquer, 2011). The interconnection of these levels indicates that chemistry education should include laboratory work (Altowaiji et al., 2021; Alvaro et al., 2019; Ho et al., 2021). Laboratory work requires students to formulate questions, create hypotheses, test these hypotheses, and draw conclusions. This process is integral to inquiry-based learning, which aims to develop students' critical thinking skills as lifelong competencies (Lau et al., 2021).

Inquiry-based learning can be classified into four levels based on the type of problem, techniques for preparing investigation procedures, and problem-solving techniques. Verification (level 0) involves the lecturer providing the problem or question, investigation method, and problem-solving approach, which students follow. Structured inquiry (level 1) allows students some independence in creating solutions, even though the lecturer provides the problem/question and investigation method. Guided inquiry (level 2) and open inquiry (level 3) grant students more independence. In guided inquiry, students develop investigation methods and problem-solving approaches based on questions posed by the lecturer. In open inquiry, students devise problems, investigation methods, and problem-solving approaches (Fay et al., 2007).

According to several researchers, the application of inquiry-based learning differs between higher education and high school. In higher education, applying guided and open inquiry is more recommended than level 1. To introduce levels 2 and 3, the lecturer can use level 1 to implement inquiry (Baur & Emden, 2020; Sedwick et al., 2018; Winkelman et al., 2015). Several studies have examined the application of guided inquiry in high school students (Orosz et al., 2023; Zion & Mendelovici, 2012). In higher education, the application of inquiry-based learning has long been practiced in some developed countries. Analyses related to inquiry skills are necessary for the development of inquiry-based teaching and learning (Teo & Goh, 2019). In Slovakia, an analysis of the implementation of inquiry-based learning (IBL) was conducted, even though IBL has been implemented in this country since 2008. The results of the inquiry skills test showed relatively low scores in argumentation skills but the best achievements in the skills of designing experiments and identifying variables (Jeskova et al., 2018). In America, inquiry projects are often used to improve students' writing skills and knowledge acquisition (Byker et al., 2017; Li et al., 2017).

Several studies have reported the benefits of inquiry-based learning on cognitive, psychomotor, and affective development. In the cognitive domain, inquiry-based learning can improve students' learning outcomes, problem-solving abilities, and thinking skills (Conway, 2014; Sedwick et al., 2018; Tornee et al., 2019; Wang et al., 2022). Through the ability to design investigations, inquiry-based learning can improve students' psychomotor skills in the laboratory, such as procedural, observational, and manipulation skills (Winkelmann et al., 2015). In the affective domain, the application of inquiry-based learning can foster positive attitudes and self-regulated learning, which can influence learning outcomes in the cognitive and psychomotor domains (Eltanahy & Forawi, 2019; Haozhi Xu & Talanquer, 2013; Kadioglu-Akbulut & Uzuntiryaki-Kondakci, 2021). For teachers, inquiry-based learning can provide experience in developing learning materials and improving teaching skills (Cheung, 2011).

Although it benefits students and teachers, implementing inquiry-based learning can be challenging in chemistry education. Teachers face challenges that need to be considered to achieve maximum learning processes in the classroom. Implementing inquiry-based learning is challenging due to large class sizes and time constraints (Kang & Keinonen, 2016; Oliveira et al., 2021). Additionally, using high-level inquiry, such as open and guided inquiry, is less effective for students with minimal prior knowledge (Szalay and Tóth, 2016).

The challenges of implementing inquiry, as described previously, can be overcome by strengthening prior knowledge or familiarizing students with scientific thinking (Baur & Emden, 2020). Using inquiry in stages, from a low to a high level, can help students become accustomed to systematic thinking by connecting their initial knowledge with newly acquired knowledge (Wildan et al., 2019). However, reports on the implementation of stepwise inquiry-based learning are only emerging. Current reports on the application of inquiry-based learning still mainly focus on using one of the previously described levels of inquiry.

Analyzing the implementation of learning is crucial to improving the learning process, especially in the post-pandemic era. In Indonesia, students are still transitioning to face-to-face learning after the pandemic. This research aims to explore the implementation of stepwise inquiry in higher education. We formulated the following research questions: (1) Can students succeed in stepwise inquiry? (2) What is the average performance of students at each stage of the inquiry process in the implementation of stepwise inquiry? (3) Is there a difference in the critical thinking scores between students who are successful and those who are unsuccessful in the inquiry? (4) Is there a difference in the self-assessments of successful and unsuccessful students in the inquiry?

# 2 Research methods

## 2.1 Description of theme and questions

### 2.1.1 Structured inquiry

The theme used in this research is "Enzymes in Everyday Life." In Mataram, pineapple and papaya are used in traditional coconut oil production to separate oil and water from coconut milk. Pineapple is more commonly used because it is easier for the public to obtain. Both pineapple and papaya contain protease enzymes that can break down the protein layer in coconut milk. Problem: Provide a method to determine the activity of the protease enzyme in pineapple.

### 2.1.2 Guided inquiry

Enzymes require optimal conditions to function effectively. Different conditions, such as temperature, soaking time for coconut milk and pineapple, and the amount of pineapple used, can affect enzyme activity. Problem: Provide a method to determine the optimal conditions for pineapple protease.

### 2.1.3 Learning scenario

The stepwise inquiry-based learning described in this research involves progressing from a low to a higher level of inquiry (Table 1). The research utilized structured inquiry (level 1) and guided inquiry (level 2).

Each level of inquiry carried out resulted in the group being categorized into two groups: successful (SG) and unsuccessful (UG). Groups were declared successful in enzyme isolation experiments if they were able to follow all stages of isolation and obtain protease enzymes with activity that was the same as or close to the activity of protease enzymes according to the formulated hypothesis. A group was considered successful at level 2 if they

**Table 1:** Scenario of stepwise inquiry learning.

| No. | Phase | Stage |
|---|---|---|
| 1 | Level 1 (structured inquiry) | 1. The lecturer introduces the draft to students as introductory knowledge.<br>2. The lecturer presents questions or themes for students to discuss.<br>3. The lecturer assists students in formulating hypotheses based on the questions provided.<br>4. The lecturer provides an investigation procedure.<br>5. Students conduct investigations following the procedures provided by the lecturer.<br>6. Students gather and analyze data.<br>7. Students present the results of their inquiry and respond to questions on the worksheet. |
| 2 | Level 2 (guided Inquiry) | 1. The lecturer introduces the draft to students as introductory knowledge.<br>2. The lecturer provides questions or themes for students to discuss.<br>3. The lecturer instructs students to formulate a hypothesis based on the questions.<br>4. Students design investigations based on the lecturer's instructions in groups.<br>5. Students conduct the investigations as planned in their groups.<br>6. Students collect and analyze data.<br>7. Students report the investigation results and answer questions on the worksheet. |

were able to carry out the investigation design as planned and obtain optimal conditions for the use of protease enzymes in accordance with the hypothesis.

#### 2.1.4 Types and samples of research

The research design utilized quantitative research methods (Creswell, 2009) to analyze the implementation of stepwise inquiry, students' ability to answer critical thinking questions, and their responses. The research sample consisted of 73 students studying biochemistry divided into three classes (Table 2).

#### 2.1.5 Research instrument

This research uses three instruments: an inquiry process assessment rubric, a critical thinking test, and a student response questionnaire. The three instruments have been previously validated through expert judgment and tested on respondents, allowing them to be used as standardized measuring instruments. The inquiry process assessment rubric uses a modified rubric from Orosz et al. (2023) with assessment levels up to level 4 according to the measured inquiry subskill. This study measures 11 subskills: problem interpretation, observation, formulating hypotheses, developing investigation designs, implementing investigation designs, using laboratory equipment, collecting data, analyzing data, developing conclusions, teamwork, and communication skills (Supplementary Materials). The instrument's reliability shows a Cronbach's alpha value of 0.806, which is acceptable. The critical thinking test uses a modified instrument from Danczak et al. (2020). The measured indicators include making assumptions, developing hypotheses, testing hypotheses, developing conclusions, and analyzing arguments. Each indicator consists of 3–5 questions. The reliability of the critical thinking instrument shows that the instrument can be used (Cronbach's alpha = 0.817). The student response questionnaire includes three indicators: the inquiry activities carried out, student inquiry skills, and collaboration with the team. A total of 3–5 statements represent each indicator of the student response instrument (Table 3). There are five answer choices: strongly disagree, disagree, unsure, agree, and strongly agree – Cronbach's alpha calculation of 0.765 shows that the questionnaire is available as a research instrument.

#### 2.1.6 Data collection technique

A total of 14 groups, each consisting of 5–6 members, from three classes participated in this study. The groups were formed heterogeneously based on gender and test results in the organic chemistry course, which served as a prerequisite for biochemistry. Each group was composed of members with varying genders and test results. The stepwise inquiry was conducted over one semester (14 weeks @ 150 min), with one lecturer assigned to each class.

**Table 2:** Demographics sample study.

| | Amount | % |
|---|---|---|
| *Gender* | | |
| Man | 12 | 16.4 |
| Woman | 61 | 83.6 |
| *Age* | | |
| 18 years | 30 | 41.1 |
| 19 years | 43 | 58.9 |
| *Gender (Age)* | | |
| Man (18 y) | 2 | 2.7 |
| Woman (18 y) | 28 | 38.4 |
| Man (19 y) | 10 | 13.7 |
| Woman (19 y) | 33 | 45.2 |

**Table 3:** The student response instrument.

| Code | Statement |
|---|---|
| S1 | I Engaged in learning activities that were new to me. |
| S2 | I Am pleased to have the opportunity to participate in these learning activities. |
| S3 | I Feel that my initial knowledge is adequate to solve the problems presented by the lecturer. |
| S4 | I Understand the learning process that I am involved in. |
| S5 | The learning process I engaged in was easy to follow. |
| S6 | Developing a hypothesis was easy for me. |
| S7 | Creating an investigation design was straightforward for me. |
| S8 | I Am familiar with the tools required for investigations. |
| S9 | I Know how to use research tools correctly. |
| S10 | I Can quickly draw conclusions based on the investigations I conduct. |
| S11 | I Enjoy working collaboratively in a team. |
| S12 | My group members listen to my ideas. |
| S13 | My group works efficiently together. |
| S14 | Each member of my group contributes equally. |
| S15 | I Have sufficient time to complete critical thinking questions. |
| S16 | I Followed the same pattern of inquiry activities in both investigations. |
| S17 | The experiments we conducted helped me solve important thinking problems. |

Prior to implementing the stepwise inquiry, each observer attended a workshop on learning scenarios and research instruments. Before and after the implementation of stepwise inquiry, students took a critical thinking test. Additionally, students completed a response questionnaire after the learning process was completed.

# 3 Results and discussion

## 3.1 Results

At the lowest level of inquiry, structured inquiry, students were instructed to isolate and determine the activity of the protease enzyme from pineapple fruit. While all groups were able to follow the investigation procedures provided by the lecturer, only three groups completed all stages of the inquiry successfully. These groups were able to isolate the enzyme, measure its activity, and calculate its activity accurately. Two groups progressed through several stages of the protease isolation process but were unable to measure the enzyme activity. Other groups needed to improve their thoroughness in measuring protease activity. Students who did not succeed were given the opportunity to repeat the process to improve their understanding.

The structured inquiry process served as the foundation for the guided inquiry process. In the second investigation using guided inquiry (level 2), six groups successfully followed the investigation process and obtained data to answer the research questions. However, eight groups needed to improve their adherence to the inquiry stages.

The analysis of the inquiry implementation rubric assessment revealed varying averages for all the assessed inquiry stages. Subskills such as collaboration, communication, data collection, equipment use, and experimental design implementation scored higher than other subskills. The stages involving problem interpretation, observation, experimental design, hypothesis formulation, data analysis, and conclusion development still need improvement. Hypothesis formulation showed the lowest average compared to other inquiry processes (Figure 1).

In the inquiry activities, we analyzed the critical thinking scores and student responses from two groups: the successful group (SG) and the unsuccessful group (UG). The SG's critical thinking N-Gain was 34.58 (SD = 1.827), while the UG's was 25.96 (SD = 2.569). Levene's test indicated homogeneous variance with a calculated $t$-value of 2.827 ($p < 0.05$), indicating a significant difference in the average critical thinking skills between the two groups.

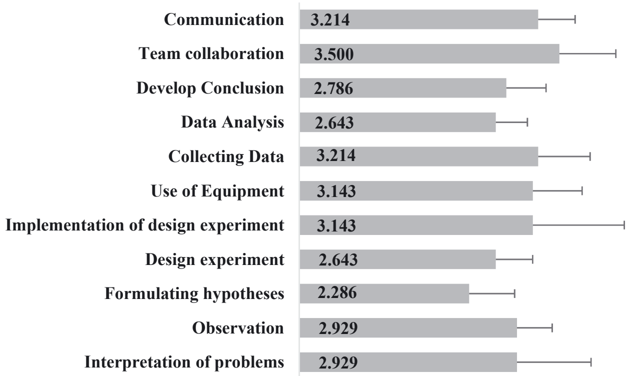


**Figure 1:** Average inquiry subskill score graded.

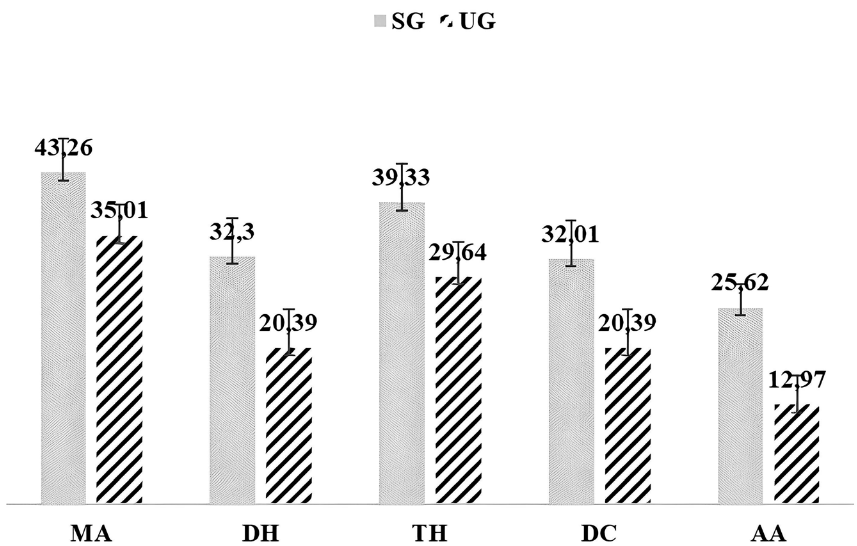


**Figure 2:** N-Gain of skills think critical SG and UG.

The analysis of each critical thinking indicator revealed that SG had a higher average N-Gain than UG. The indicators with the highest and lowest average N-Gain for both groups were making assumptions and argument analysis, respectively (Figure 2).

The average response scores of the successful group (SG) and unsuccessful group (UG) showed a significant difference, with a calculated t-value of 7.575 ($p < 0.05$). The average score of SG ($M$ = 3.344; SD = 0.215) was higher than that of UG ($M$ = 2.219; SD = 0.829) (Table 4).

After implementing stepwise inquiry in this study, an analysis regarding the ability to answer critical thinking questions is necessary. In the category of making assumptions, students struggled with understanding the implied meaning in the questions and providing reasons for the validity or invalidity of their chosen assumptions. Approximately 36.91 % of students answered by simply restating the given questions without conducting a proper analysis. Additionally, 26.03 % answered 'I don't know' without providing reasons for their responses.

In the category of developing a hypothesis, students' ability to make decisions based on information from the provided paragraphs was assessed. Each paragraph aimed to guide students in formulating temporary answers based on their analysis. However, 38.35–69.86 % of students provided choices with inappropriate reasons for this question, with more than 20 % not providing any reasons for their answers. Regarding the testing of hypotheses, students showed a tendency to make more reasonable deductions, although the percentage of non-answers was higher compared to the category of developing a hypothesis.

In the categories of developing conclusions and argument analysis, which are indicators with the fewest number of students providing correct answers, students' ability to derive valid conclusions from the law and

**Table 4:** Average score of SG and UG statements.

| Statement | SG | | UG | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| S1 | 3,000 | 0.354 | 1,950 | 1,011 |
| S2 | 3,273 | 0.452 | 2,525 | 1,261 |
| S3 | 3,061 | 0.348 | 2,375 | 1,125 |
| S4 | 3,121 | 0.415 | 2,125 | 1,067 |
| S5 | 3,364 | 0.489 | 2,075 | 1,118 |
| S6 | 3,636 | 0.489 | 2,450 | 1,061 |
| S7 | 3,455 | 0.506 | 2,150 | 1,167 |
| S8 | 3,030 | 0.305 | 2,475 | 1,154 |
| S9 | 3,000 | 0.250 | 2,125 | 1,067 |
| S10 | 3,424 | 0.502 | 2,075 | 1,141 |
| S11 | 3,515 | 0.508 | 2,450 | 1,085 |
| S12 | 3,758 | 0.435 | 2,125 | 1,159 |
| S13 | 3,394 | 0.556 | 2,375 | 1,148 |
| S14 | 3,545 | 0.506 | 2,100 | 1,057 |
| S15 | 3,545 | 0.564 | 2,075 | 1,141 |
| S16 | 3,576 | 0.502 | 2,475 | 1,086 |
| S17 | 3,152 | 0.364 | 1,800 | 0.853 |

observation results presented in the paragraphs needs improvement. Only around 19.52 % of students were able to answer and analyze correctly, with 31.17 % not answering, and the rest providing answer choices without reasons. In questions related to enzyme analysis, students demonstrated the highest percentage of correct answers in argument analysis. Approximately 42.46 % of students correctly calculated the $K_m$ and $V_{max}$ values and explained their results.

## 4 Discussion

The gradual introduction of inquiry-based learning in higher education enhances students' foundational knowledge, making it easier for them to engage in higher-level inquiry activities. However, inquiry activities, particularly the investigation stage, faced challenges during the ongoing pandemic. As face-to-face learning resumes, cognitive, social, and process elements are reintroduced into the learning process. This situation has led to the adoption of inquiry-based learning in biochemistry education, as it is believed to reintroduce these essential elements into science learning (Lau et al., 2021; Willey et al., 2020).

The use of stepwise inquiry provides students with the opportunity to practice basic investigative skills, thereby enhancing their overall learning experience. Structured inquiry (level 1) serves as a foundational stage to reinforce basic inquiry skills, helping students improve their procedural skills, especially in accurately interpreting and executing inquiry instructions. According to Sebesta and Bray Sperh (2017), failure at this stage encourages students to adopt new strategies, leading to improved performance in subsequent stages. The successful implementation of guided inquiry after structured inquiry serves as a means to further enhance students' investigative skills.

There has been an increase in the number of groups successfully conducting investigations using the guided inquiry approach. Six groups successfully demonstrated the theory explaining the factors influencing the activity of the protease enzyme. Interestingly, four groups that succeeded in the second investigation using guided inquiry had previously failed at the structured inquiry stage. This suggests that the structured inquiry stage provides students with initial knowledge and experience that better prepare them for conducting investigations. Previous research emphasizes the importance of prior knowledge in determining learning success

(Dong et al., 2020; Thurn et al., 2022). An investigation is more beneficial when students have some initial knowledge related to the investigation (van Riesen et al., 2018).

The groups that successfully conducted the second investigation using guided inquiry were more active in creating experimental designs and preparing for the investigation process. This aligns with Limoto & Frederick's (2011) assertion that activities involved in preparing an investigation design can increase the likelihood of investigation success. A well-planned investigation can enhance activity and the ability to prepare everything needed for the investigation process (Burnham, 2013; Miller & Lang, 2016; Walker & Sampson, 2013).

The analysis of subskill abilities reveals that the collaboration team subskill has the highest average, while the formulating hypotheses subskill has the lowest average. Research by Orosz et al. (2023) and Garzia-Carmona (2020) emphasizes the critical nature of formulating hypotheses in inquiry-based learning. In developing a hypothesis, students require initial knowledge to search for information, making it easier for them to describe the possible results of the investigation (Wang et al., 2022). Insufficient information search and a lack of interpretation skills may contribute to low hypothesis-formulating abilities (Aydogdu, 2015).

The group that successfully completed the inquiry stage had higher critical thinking scores than the group that failed to do so. Several studies suggest that while experimental skills may have a limited impact on students' understanding of concepts and thinking skills (Etkina et al., 2010), laboratory skills can enhance critical thinking skills. Students who succeeded in the inquiry stage demonstrated better laboratory skills than those who failed, leading to higher critical thinking scores in the successful group (SG) compared to the unsuccessful group (UG).

The development of a hypothesis received the lowest score in both the SG and UG groups. Consistent with research by Danczak et al. (2020), the development of a hypothesis indicator typically yields low scores in measuring students' critical thinking skills. Factors influencing students' ability to develop hypotheses include prior knowledge and information analysis skills (Frerejean et al., 2016; van Riesen et al., 2018). However, prior knowledge alone does not always determine the ability to develop a reasonable hypothesis. Providing partial hypotheses can also affect students' success in improving this indicator (Kuang et al., 2020). Practicing numerous examples of hypothesis development in responding to critical thinking questions is believed to enhance students' skills in this area. Further investigation is needed to determine the cause of the low scores in the hypothesis development indicator. Notably, the SG group demonstrated a better performance in answering critical thinking questions than the UG group.

Analysis of student responses to the inquiry implementation showed that the SG group had a higher average score compared to the UG group. All statements in the SG group received higher scores than those in the UG group. A high score in student statements indicates positive feelings, which can lead to increased motivation and self-confidence (Cheung, 2011). According to Galloway and Bretz (2015), the psychomotor domain relies on students' ability to inquire about their previous feelings. Furthermore, failure in the previous stage can motivate students to develop better learning strategies (Zheng & Zhang, 2020).

Previous research has reported the relationship between the affective domain and achievement in the cognitive and psychomotor domains. Affective domains such as feelings, motivation, confidence, and other emotional states affect students' cognitive and psychomotor achievement (Kuo et al., 2024). This study showed that SG had the highest score on the response questionnaire, indicating that SG had positive feelings towards the learning implementation. This may affect the ability to plan investigations and the achievement of critical thinking scores involving students' cognitive processes. Research by Knöbel et al. (2024) explained that affective and emotional states are related to body coordination, which is connected to the psychomotor domain. The implementation of laboratory investigations involves the psychomotor domain, which is associated with positive feelings. Additionally, students' ability to conduct investigations is also related to their general cognitive abilities (Kruit et al., 2018).

## 5 Conclusions

Our research explored the implementation of stepwise inquiry using levels 1 and 2. While students were able to conduct inquiry procedures and develop an inquiry design, only three groups were successful at level 1, and six groups at level 2. Analysis of the inquiry stage subskills shows that the collaboration team subskill shows the highest score, while the formulating hypothesis subskill shows the lowest score. The SG group had significantly different critical thinking scores. The two groups' highest and lowest average N-gains are shown respectively in the making assumption and argument analysis indicators. Analysis of student responses showed that the successful group (SG) gave the highest average score compared to the unsuccessful group (UG).

**Research ethics:** Not applicable.
**Author contributions:** The authors have accepted responsibility for the entire content of this manuscript and approved its submission.
**Competing interests:** The authors state no conflict of interest.
**Research funding:** None declared.
**Data availability:** Not applicable.

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**Supplementary Material:** This article contains supplementary material (https://doi.org/10.1515/cti-2023-0081).