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From Participation to Critical Thinking: The Role of a Mind Map-Based Constructive Collaborative Approach in Learning the Human Reproductive System

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A B S T R A C T

Limited critical thinking skills and low participation in biology learning often result in fragmented and less meaningful conceptual understanding. This study aimed to evaluate the effectiveness of a mind map-based constructive collaborative approach in improving students' critical thinking skills and participation in learning the human reproductive system. A quasi-experimental study employing a non-equivalent control group pretest–posttest design was conducted with 72 eleventh-grade high school students. Data were collected using a critical thinking test, the Student Engagement Scale, classroom observations, and analyses of collaborative mind maps. The findings revealed that students in the experimental group achieved greater improvement in critical thinking skills than those in the control group, with N-Gain scores of 0.687 and 0.544, respectively, and the difference was statistically significant (Mann–Whitney, $p < 0.001$). Student participation also increased more substantially in the experimental group, particularly in the agentic and cognitive engagement dimensions. Spearman correlation analysis indicated a significant positive relationship between critical thinking skills and student participation ($r_s = 0.392$, $p = 0.001$). Qualitative findings further demonstrated improvements in conceptual integration, scientific argumentation, and active engagement. These findings suggest that a mind map-based constructive collaborative approach effectively promotes higher-order thinking skills and active participation in biology learning.

1. Introduction

Critical thinking skills are an essential competency in biology learning because they help students analyze, evaluate, and meaningfully integrate scientific concepts. Empirical evidence indicates that students' critical thinking skills in biology remain unsatisfactory. A study involving 260 eleventh-grade students reported that 53.46%

of students demonstrated very low critical thinking skills and only 3.07% achieved high or very high levels when learning the endocrine system, another conceptually complex and abstract biology topic (Sari & Yulianti, 2024). Similar conceptual difficulties are also found in learning the human reproductive system. Previous research reported that 35% of students experienced misconceptions about menstruation, 30% about ovulation, and 25% about fertilization-related concepts, indicating persistent difficulties in understanding interconnected reproductive processes (Salsabilla & Melta, 2025).

Therefore, various studies indicate that students' critical thinking skills remain limited, particularly in complex and abstract topics such as the human reproductive system (Fauzi et al., 2021; Fuad et al., 2017; Nadya et al., 2021). This condition causes the understanding of biological concepts to tend to be partial and gives rise to misconceptions, especially regarding the relationship between concepts such as hormonal regulation, gametogenesis, fertilization, and the reproductive cycle (Nuraini & Antika, 2024; Salsabilla & Melta, 2025). In fact, the concept of the reproductive system is hierarchical and integrated so that critical thinking skills are needed to build a complete biological understanding (Susetyarini et al., 2023).

Students' low critical thinking skills are closely related to their low participation during the learning process. Biology instruction in schools is still dominated by teacher explanations, so students tend to be passive recipients of information (Banjarnahor & Aryeni, 2025; Hernández-Barco et al., 2021). As a result, students have limited opportunities to engage in scientific activities such as asking questions, presenting arguments, evaluating information, and discussing concepts in depth. This condition causes learning to be more oriented towards memorization than developing higher-order thinking skills. As a consequence, students have fewer opportunities to construct knowledge actively, which limits the development of analytical reasoning and higher-order thinking skills.

Theoretically, active student participation plays a vital role in developing critical thinking skills. Student involvement in collaborative discussions allows for the elaboration of concepts, negotiation of meaning, and evaluation of information based on scientific evidence (Lv et al., 2022). This interaction helps students revise their initial understanding to become more logical and structured through scientific discussion and argumentation. Furthermore, active student engagement also supports the retrieval process, which helps strengthen memory traces and long-term retention of biological concepts (Damayanti et al., 2024; Endres et al., 2024). Therefore, student participation is not only seen as a form of behavioral involvement, but also as a cognitive mechanism that supports the development of critical thinking skills.

One approach considered relevant to support this process is constructive collaborative learning. This approach is rooted in the theory of social constructivism, which emphasizes that knowledge is constructed through social interaction, dialogue, and cooperation between individuals (Vygotsky, 1978). This approach encourages students to build understanding collaboratively through discussion, scientific argumentation, and reflection, thus supporting the

development of higher-order thinking processes (Haryono et al., 2025). To support concept integration, constructive collaborative learning can be combined with the use of mind maps as a visual representation of knowledge. Mind maps help students organize and integrate complex biological concepts, while collaborative mind map creation encourages negotiation of meaning and the shared construction of knowledge (Amante et al., 2026). This activity helps students build a more coherent conceptual structure while strengthening the retention process of previously acquired knowledge (Dörrenbächer-Ulrich et al., 2024).

Although extensive research has been conducted on collaborative learning in science education, most studies have focused on learning outcomes or critical thinking skills in isolation. Research explaining how student participation functions as a pedagogical mechanism in collaborative knowledge construction remains relatively limited (Afriani & Zaman, 2026). Furthermore, studies on the integration of constructive collaborative learning and collaborative mind mapping in human reproductive system materials are still rare. Thus, there is little empirical evidence explaining how student participation acts as a pedagogical mechanism linking collaborative knowledge construction with the development of critical thinking skills.

Unlike previous studies that generally only measure learning outcomes or critical thinking skills separately, this study integrates student participation as a pedagogical mechanism in the knowledge construction process through a constructive collaborative approach based on mind maps and retention reinforcement. This integration allows students not only to actively engage in learning but also to build deeper relationships between biological concepts through scientific argumentation, negotiation of meaning, and collaborative conceptual visual representation. Mind maps also facilitate meaningful concept organization and support the development of critical thinking by helping students visualize relationships among concepts (Riska et al., 2023; Septyani et al., 2026).

Therefore, this study aims to: (1) analyze the influence of the constructive collaborative approach on students' critical thinking skills; (2) analyze the influence of this approach on students' participation levels; and (3) identify the relationship between critical thinking skills and students' participation levels during Reproductive System learning. This study is expected to provide empirical contributions in the development of Biology learning that is more participatory, meaningful, and oriented towards the development of higher-order thinking skills

2. Methodology

This study used a quasi-experimental method with a non-equivalent control group pretest–posttest design. The experimental class received learning using a constructive collaborative approach, while the control class used conventional learning. Pretests and posttests were administered to measure changes in students' critical thinking skills before and after the treatment, as shown in Table 1.

Table 1. Non-Equivalent Control Group Pretest–Posttest Design

Research Class	Intervention	Critical Thinking Skills Pretest	Critical Thinking Skills Posttest	Participation Level Pretest	Posttest Participation Level
Experiment	Constructive collaborative approach (X)	O1	O2	O3	O4
Control	Conventional learning (Y)	O1	O2	O3	O4

Information**:**
O1 : critical thinking skills pretest
O2 : posttest of critical thinking skills
O3 : pretest of student participation
O4 : posttest student participation
X : learning using a constructive collaborative approach
Y : conventional learning

Based on the research design in Table 1, the experimental class was given treatment in the form of learning using a constructive collaborative approach, while the control class received conventional learning. Measurement of critical thinking skills was carried out through pretests and posttests using instruments based on Marzano and Kendall's Taxonomy. Meanwhile, the student participation was measured before and after learning using the Student Engagement Scale, observation sheets, and peer assessment. In addition to quantitative data, this study was also supported by qualitative data in the form of collaborative mind map results, student worksheets, and video recordings of group discussions to strengthen the interpretation of the research results through data triangulation.

The study population was all eleventh-grade students in Phase F of a public high school in Bandung City studying the Reproductive System in the Biology subject of the Independent Curriculum. The study sample consisted of two eleventh-grade classes selected using a purposive sampling technique based on equivalence of academic characteristics, learning implementation, and recommendations from the biology subject teachers. One class was designated as the experimental class receiving learning using a constructive collaborative approach, while the other class was designated as the control class receiving conventional learning.

The number of research participants consisted of 72 students with an age range of 16–17 years, divided into 36 students in the experimental class and 36 students in the control class. In the experimental class there were 20 male students and 16 female students, while in the control class there were 19 male students and 17 female students. Class selection was carried out without randomization because the classes had been previously formed (intact group) so the study used a non-equivalent control group design. Before the treatment was given, both classes were first given a pretest to identify the equality of students' initial abilities. The research was conducted after obtaining approval from the school and the biology teacher.

All participants were given an explanation of the research objectives and learning procedures before the study began.

The research procedure was implemented in the experimental class using a constructive collaborative approach integrated with a retention-based strategy (Rahmat & Jamil, 2024). This approach emphasizes the process of constructing knowledge (constructive) through the activation of prior knowledge, concept exploration, and the preparation of mind maps, as well as collaborative processes (collaborative) through group discussions, scientific argumentation, negotiation of meaning, and co-construction of knowledge among students. This approach was developed based on the principles of Vygotsky's social constructivism, collaborative learning, and retention-based learning that are oriented towards strengthening students' conceptual understanding and information retention. Learning is carried out in four meetings (2 × 45 minutes) covering the structure and function of the reproductive system, gametogenesis and reproductive hormones, the menstrual cycle and fertilization, and reproductive system disorders. The stages of constructive collaborative learning in this study are presented in Table 2.

Table 2. Stages of Constructive Collaborative Learning Based on Information Retention

Stages	Learning Activities
Apperception	The teacher presents contextual biological phenomena through videos, images, and prompt questions to activate students' prior knowledge. Students make initial predictions and connect previous concepts to the reproductive system material as part of the constructive phase of the knowledge-building process.
Concept Exploration and Individual Construction	Students explore information from various learning sources to independently construct initial understanding. Next, they create individual mind maps to represent the construction of biological concepts.
Collaborative Shared Cognition	Students work collaboratively in small groups to discuss the results of their concept explorations, conduct scientific arguments, exchange ideas, clarify misconceptions, and create group mind maps. This stage emphasizes the process of constructive collaboration through the negotiation of meaning and co-construction of knowledge among students.
Concept Validation and Scaffolding	Teachers facilitate concept validation through reflective questions, scientific clarification, and conceptual scaffolding to strengthen students' collaborative knowledge construction outcomes and maintain information retention.
Reflection and Retention Reinforcement	Students conduct metacognitive reflection on changes in understanding, evaluate the group collaboration process, revise mind maps, and conclude conceptual relationships through concept reinforcement and repetition of important information as a learning retention strategy.

The stages of constructive collaborative learning based on information retention were implemented in four learning sessions on the reproductive system. Each session was designed to facilitate the gradual construction of knowledge through concept exploration, collaborative discussion, scientific argumentation, and strengthening information retention. The learning implementation in the experimental and control classes is presented in Table 3.

Table 3. Implementation of Learning in Experimental Class and Control Class

Meeting	Material	Experimental Class	Control Class
1	Structure and function of the reproductive system	Constructive collaborative learning based on mind mapping	Lectures and Student Worksheets
2	Gametogenesis and reproductive hormones	Collaborative discussion and scientific argumentation	Lectures and individual exercises
3	Menstrual cycle and fertilization	Concept analysis through collaborative mind maps	Questions and answers and LKPD
4	Reproductive system disorders	Case studies and collaborative discussions	Lectures and individual exercises

Based on the learning implementation in Table 3, the experimental class demonstrated learning that emphasized collaborative knowledge construction through group discussions, scientific argumentation, mind mapping, and metacognitive reflection. Information retention strategies were integrated through concept reinforcement and retention. Meanwhile, the control class used conventional learning dominated by teacher explanations and individual exercises. During the learning process, group discussion activities in the experimental class were recorded to support data triangulation. Critical thinking skills were measured using multiple-choice and essay test instruments developed based on The New Taxonomy of Educational Objectives proposed by Marzano and Kendall, 2007. The test was conducted using paper-based instruments, to measure the ability to understand, analyze, evaluate, and reflect on reproductive system concepts.

The multiple-choice instrument consisted of 20 questions with five answer options covering several cognitive processes, such as recognizing, recalling, integrating, classifying, decision-making, and monitoring clarity. The essay test was used to measure students' analytical skills, scientific argumentation, problem-solving, and conceptual reflection. The descriptive questions were scored using an analytical rubric with a score range of 0–4. A score of 4 was given if the answer was complete, logical, used appropriate biological concepts, and was accompanied by relevant scientific arguments. A score of 3 was given if the answer was quite complete but still contained a few conceptual errors. A score of 2 was given if the answer was still partial and the argumentation was inappropriate. A score of 1 was given if the answer was very limited and showed misconceptions. A score of 0 was given if the student did not answer or the answer did not match the question. The distribution of critical thinking skills instrument indicators based on Marzano's Taxonomy is presented in Table 4.

Table 4. Critical Thinking Skills Instrument based on Marzano's Taxonomy

Taxonomy Level	Cognitive Process	Question Number
Retrieval	Recognizing, Recalling, Executing	1–5
Comprehension	Integrating, Symbolizing	6–7
Analysis	Matching, Classifying, Analyzing Errors	8–12
Knowledge Utilization	Decision Making, Problem Solving	13–14

Metacognitive System	Specifying Goals, Monitoring Clarity	18–19
Self-System Thinking	Generalizing, Specifying, Experimenting, Examining Emotional Response	15–17, 20

Prior to use in the research, the critical thinking skills instrument was tested for validity, reliability, difficulty level, and item discrimination. The test results showed that the instrument was valid and reliable, with a Cronbach's Alpha value of 0.744 for multiple-choice items and 0.802 for descriptive items. Furthermore, the items had varying levels of difficulty and good discrimination power, making them suitable for use in the research.

The student participation was measured using the Student Engagement Scale adapted from Gunuc and Kuzu (2015). The instrument uses a rating scale of 1–9 to measure the intensity of student engagement during collaborative learning. Measurements were conducted through self-assessment and peer-assessment to increase the objectivity and validity of student participation data. The distribution of student participation instrument indicators is presented in Table 5.

Table 5. Distribution of Student Participation Instruments Based on Constructive-Collaborative

Engagement Dimensions	Item Code	Number of Items
Cognitive Engagement	CE1–CE7	7
Behavioral Engagement	BE1–BE7	7
Emotional Engagement	EE1–EE6	6
Agentic Engagement	AE1–AE8	8
Total		**28**

In addition to using questionnaires, students' participation was also directly observed during the collaborative learning process, particularly during discussion activities and mind mapping. Observations were supported by learning recordings to strengthen data objectivity. Prior to use, the student participation instrument was tested for validity and reliability, with results indicating all items were valid and reliable (Cronbach's Alpha = 0.763). Self-assessment and peer-assessment instruments were constructed using the same indicators to compare self-perceptions and peer assessments of student participation during collaborative learning.

Data analysis techniques were carried out quantitatively and qualitatively to identify the effect of the constructive collaborative approach on critical thinking skills and student participation. Quantitative data were analyzed using IBM SPSS Statistics through normality tests, homogeneity tests, N-Gain tests, paired sample t-tests, independent sample t-tests, and Spearman's rank correlation test. Meanwhile, qualitative data were analyzed descriptively through collaborative mind map interpretation and learning activity recordings to identify interaction patterns, scientific argumentation, student participation, and collaborative knowledge construction processes. Mind map analysis was conducted to identify the development of conceptual structures, relationships between concepts, concept elaboration, scientific argumentation, and student misconceptions during the learning process. The mind map assessment was carried out by two assessors, namely the researcher and the Biology teacher, using previously prepared analysis

guidelines to increase the consistency and objectivity of data interpretation. The results of the quantitative and qualitative analyses were then integrated through data triangulation to strengthen the validity of the study.

3. Results and Discussion

Effects of the Constructive Collaborative Approach on Critical Thinking Skills

The constructive collaborative approach was implemented over four learning sessions covering the structure and function of the human reproductive system, gametogenesis and reproductive hormones, the menstrual cycle and fertilization, and reproductive system disorders. During the intervention, students individually constructed initial mind maps, participated in collaborative discussions and scientific argumentation, developed collaborative mind maps, and reflected on their conceptual understanding with teacher scaffolding. In contrast, students in the control class received conventional teacher-centered instruction consisting of lectures, question-and-answer sessions, and individual exercises. Following the implementation of these learning activities, students' critical thinking skills and participation were analyzed to evaluate the effectiveness of the learning approach. Descriptive analysis indicated that critical thinking scores increased markedly in the experimental class compared with the control class following the learning intervention. In the experimental class, the average score increased from 50.56 (pretest) to 86.22 (posttest), while in the control class it increased from 45.03 to 78.47. These results indicate that constructive collaborative learning has a positive influence on students' critical thinking skills in the human reproductive system material. A comparison of the pretest and posttest scores of the two classes is presented in Figure 1.

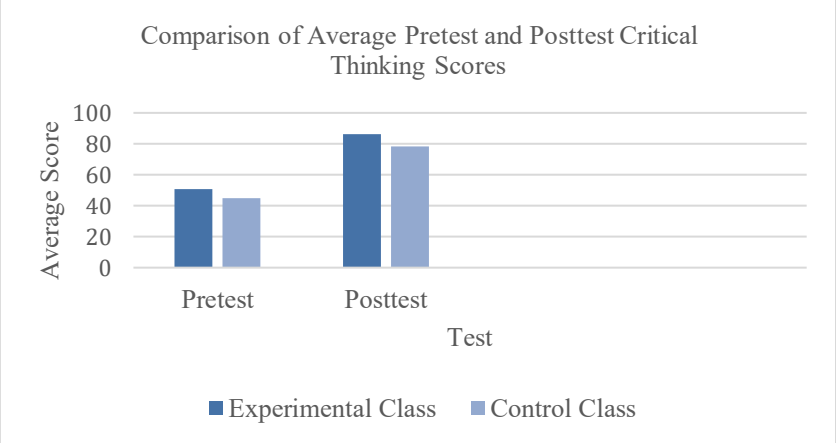

Figure 1. Comparison of Mean Pretest and Posttest Critical Thinking Scores of the Experimental and Control Classes.

Before the hypothesis test was conducted, the data were first tested for normality using the Shapiro–Wilk test. The test results showed that the posttest data for the experimental class was normally distributed (Sig. = 0.160 > 0.05), while the control

class was not normally distributed (Sig. = 0.011 < 0.05). Therefore, the analysis was continued using the Mann–Whitney test. The improvement in students' critical thinking skills was then analyzed using the N-Gain score presented in Table 6.

Table 6. Results of N-Gain Analysis of Critical Thinking Skills

Group	Mean N-Gain	Standard Deviation	Category
Experiment	0.687	0.168	Moderate–High
Control	0.544	0.218	Moderate

Based on Table 6, the experimental class obtained an average N-Gain of 0.687 with a moderate-to-high category, while the control class obtained an average N-Gain of 0.544 with a moderate category. Furthermore, the difference in critical thinking skills between the experimental and control classes was analyzed using the Mann–Whitney test as shown in Table 7.

Table 7. Results of the Mann-Whitney Test of Critical Thinking Skills in the Experimental Class and the Control Class

Variables	Sig.	Decision	Information
N-Gain Critical Thinking Skills	$p < 0.001$	H_0 rejected	There is a significant difference

The Mann–Whitney test showed a significant difference in the increase in critical thinking skills between the experimental class and the control class ($p < 0.05$).

Effect of the Constructive Collaborative Approach on Student Participation

Descriptive analysis showed that the student participation in the experimental class increased significantly compared to the control class after the learning process. The average student participation score in the experimental class increased from 125.44 to 194.39, while in the control class it increased from 127.83 to 146.25. A comparison of the pretest and posttest scores for student participation in both classes is presented in Figure 2.

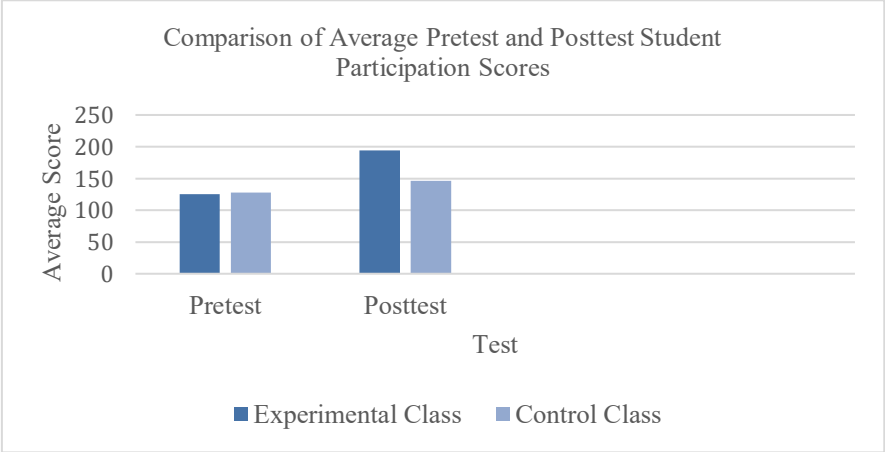

Figure 2. Comparison of Mean Pretest and Posttest Scores of Student Participation

Figure 2 shows the differences in student participation scores between the experimental and control classes. To provide a more detailed interpretation of student engagement, each engagement dimension was further analyzed, as presented in Figure 3.

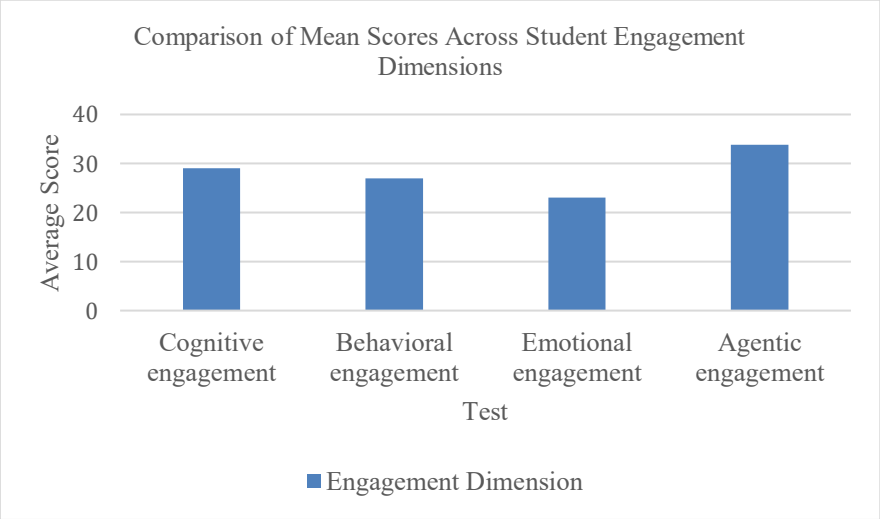

Figure 3. Comparison of Mean Scores Across Student Engagement Dimensions

The analysis results showed that the agentic engagement dimension obtained the highest mean score (Mean = 33.82), followed by cognitive engagement (Mean = 28.99). Meanwhile, the behavioral and emotional engagement dimensions were categorized as moderate to high. Furthermore, to identify the consistency of student participation measurements, a correlation test was conducted between self-assessment and peer-assessment results using the Spearman test in Table 8.

Table 8. Spearman Correlation Test Results between Self-Assessment and Peer-Assessment

Variables	Correlation Coefficient (r_s)	Sig.	Interpretation
Self-Assessment↔ Peer-Assessment	0.965	< 0.001	The positive relationship is very strong

The results of the Spearman correlation test showed a very strong positive relationship between self-assessment and peer-assessment with a correlation coefficient of 0.965 and a significance value of 0.000 ($p < 0.05$).

Results of the Relationship between Critical Thinking Skills and Student participation

The relationship between critical thinking skills and student participation was analyzed using the Spearman correlation test. The results of the correlation test are presented in Table 9.

Table 9. Spearman Correlation Test Results between Critical thinking skills and Participation Level

Variables	Correlation Coefficient (r_s)	Sig.	Interpretation
Posttest CT ↔ Posttest Engagement	0.392	0.001	Moderate positive relationship

Spearman correlation analysis revealed a significant positive relationship between critical thinking skills and student participation with a correlation coefficient of 0.392 and a significance value of 0.001 ($p < 0.05$).

Effect of the Constructive Collaborative Approach on Critical Thinking Skills

Research shows that the mind map-based constructive collaborative approach can improve students' critical thinking skills better than conventional learning. This improvement is evident from the higher N-Gain value of the experimental class compared to the control class and the significant difference based on the Mann–Whitney test. These findings indicate that collaborative discussion activities and active knowledge construction help students analyze, evaluate, and integrate biological concepts more deeply.

These findings are in line with Vygotsky's social constructivism theory, which emphasizes that the development of higher-order thinking skills is formed through social interaction, dialogue, and collaboration between students (Vygotsky, 1978). In group discussions, students negotiate meaning, defend scientific arguments, and evaluate peer opinions, resulting in cognitive conflict that encourages knowledge restructuring. Collaborative learning enables students to construct shared understanding through shared cognition, the collective exchange of ideas and information processing that contributes to the development of critical thinking skills.

The results of this study are also supported by several recent studies showing that constructivism-based collaborative learning can improve students' higher-order thinking skills. Collaborative discussion activities and scientific argumentation in science learning contribute to improving students' analytical and evaluation skills (Chusni et al., 2020). Similar improvements in critical thinking have also been reported through the implementation of innovative student-centered learning models, including the Spatial Problem-Based Learning model, which encourages students to analyze problems, evaluate evidence, and actively construct knowledge during the learning process (Andini et al., 2025). Furthermore, collaborative interactions allow students to elaborate concepts and engage in deeper cognitive reflection, thus supporting the development of critical thinking skills. The use of mind maps in biology learning helps students connect complex concepts more systematically and improves their knowledge organization skills (Nuraini & Antika, 2024).

Qualitative data in the form of student mind maps reinforces the quantitative findings of this study. Individual mind maps at the beginning of the lesson generally

still show simple, linear conceptual relationships, limited to the basic definitions of reproductive organs, as shown in Figures 4 and 5. Most students still construct concepts separately without demonstrating the in-depth relationships between biological processes. This condition indicates that students' initial understanding is still at the conceptual introduction stage and has not yet formed a complex conceptual structure.

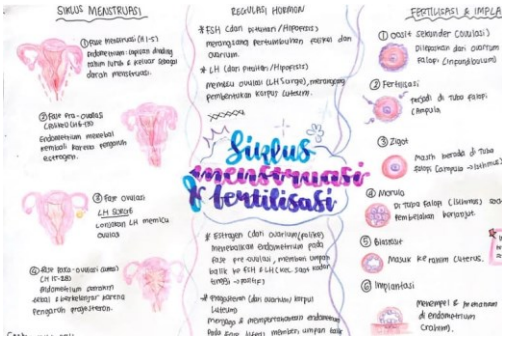

Figure 4. Mind Map Individual Students Sub-Material Menstrual Cycle & Fertilization

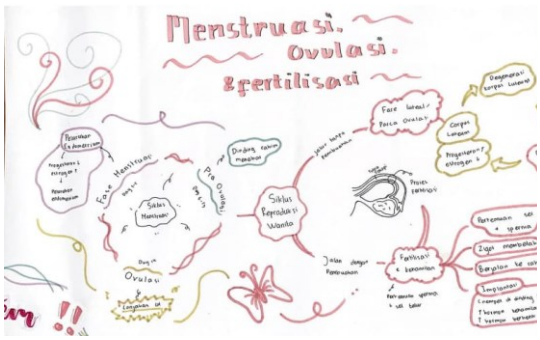

Figure 5. Mind Map Student Group Sub-Material Menstrual Cycle & Fertilization

The analysis results show the development of students' conceptual structure from individual mind maps to collaborative mind maps on the topic of the menstrual cycle, hormone regulation, and fertilization. This development is seen in the aspects of concept elaboration, relationships between biological concepts, scientific argumentation, and the complexity of the conceptual structure built by students during the constructive collaborative learning process. In individual mind maps, students have been able to identify the main stages of the menstrual cycle such as menstruation, ovulation, and the luteal phase, but the relationship between biological processes has not been explained in depth. The conceptual structure appears to be still linear with limited relationships between concepts. Several important concepts such as the regulation of estrogen, progesterone, FSH, and LH hormones begin to emerge, but the relationship between hormonal mechanisms with endometrial changes and the fertilization process has not been fully integrated.

Furthermore, the explanations in individual mind maps are still descriptive and focus more on the basic definitions of each reproductive phase. Biological elaboration related to the processes of fertilization, implantation, and hormonal cause-and-effect relationships has not developed optimally. This condition indicates that students still experience difficulty integrating abstract and complex concepts in the human reproductive system. Meaningful learning occurs when students actively build connections between new concepts and prior knowledge through the processes of organization, elaboration, and integration of information, resulting in a deeper conceptual understanding (Krieglstein et al., 2022). The low conceptual connectivity in individual mind maps indicates that the process of integrating students' knowledge is still limited to the basic conceptual level.

In contrast to individual mind maps, collaborative mind maps demonstrate the development of a more integrative and elaborate knowledge structure. Students begin to connect the menstrual cycle with hormonal regulation, ovulation, fertilization, and implantation as a single, interrelated biological process. Conceptual relationships are more clearly visible through the use of concept branches, relationship arrows, and systematic grouping of reproductive phases. These findings indicate that the collaborative process helps students build more comprehensive and in-depth connections between biological concepts.

Overall, the results of the mind map analysis indicate that collaborative learning activities can encourage increased conceptual elaboration, interconnectedness between biological concepts, scientific argumentation, and students' conceptual structures. These findings support the quantitative results of the study, which showed an increase in critical thinking skills and student participation after the implementation of the constructive collaborative approach. Thus, the integration of collaborative learning and mind maps not only helps students understand biological concepts more deeply but also supports the development of higher-order thinking skills through an active and meaningful process of knowledge construction. Thus, the integration of the constructive collaborative approach and collaborative mind mapping not only improves learning outcomes quantitatively, but also shows the development of students' thinking quality through a more complex, integrative, and meaningful knowledge construction process.

The Effect of the Constructive Collaborative Approach on Student participation

Research shows that a constructive collaborative approach based on collaborative mind maps can improve student participation better than conventional learning. This improvement is evident in the average student participation score in the experimental class, which increased significantly compared to the control class. This finding indicates that learning involving collaborative activities and active knowledge construction can create higher student engagement throughout the learning process.

The increased student participation in the experimental class confirms that constructive collaborative learning successfully creates a student-centered learning environment (Salsabila et al., 2026). In this approach, students not only receive information from the teacher but also play an active role in constructing knowledge through group discussions, exchange of ideas, scientific argumentation, and collaborative mind mapping. These activities provide space for students to engage cognitively, socially, and emotionally during the learning process. This finding aligns with the student engagement theory, which states that student engagement in learning increases when students are given the opportunity to actively participate in the knowledge construction process through meaningful interactions, discussions, and learning activities (Fredricks et al., 2004).

The research results show that the agentic engagement dimension scored highest compared to other dimensions. These findings indicate that students actively participated in learning by conveying ideas, arguing scientifically, providing

responses, and contributing to guiding group discussions. High levels of agentic engagement reinforce the notion that students are beginning to develop the courage to express their opinions and participate in decision-making during the learning process (Mameli & Passini, 2019). This condition illustrates that constructive collaborative learning is able to provide wider participation space for students compared to conventional learning which tends to be teacher-centered.

Furthermore, the cognitive engagement dimension also showed a high category, indicating that students were actively involved in the process of concept elaboration and knowledge construction during collaborative mind mapping. The mind mapping activity encouraged students to organize information, connect biological concepts, and reflect on the conceptual relationships learned. The use of visual representations in mind maps helped students process information more deeply, thereby increasing cognitive engagement during learning. This finding aligns with research by Krieglstein et al. (2022) which stated that concept visualization through concept mapping helps students elaborate concepts and integrate knowledge more meaningfully. These quantitative findings are reinforced by observations of classroom learning activities and documentation of the collaborative mind map development process, as shown in Figure 6.

Figure 6. Student Learning Activity Recording

Based on the analysis of recorded learning activities, students were seen actively involved in group discussions during collaborative assignment preparation. Student activities demonstrated social interaction, cooperation between students, and cognitive engagement in building conceptual understanding together. These findings align with research that suggests collaborative learning can increase student engagement through discussion activities, idea exchange, and collaborative problem-solving, thereby encouraging cognitive and social engagement throughout the learning process (Sun et al., 2022).

During the learning process, students were seen actively discussing, seeking additional information through digital devices, providing scientific arguments, and dividing tasks within groups. In some groups, some students played a role in creating mind maps, while others provided input, sought additional references, and clarified relationships between biological concepts. This pattern demonstrates collaboration and role-sharing that support student engagement in the learning process. Students' active involvement in expressing ideas, providing responses, and

contributing to the learning process constitutes agentic engagement, demonstrating students' active participation in constructing their own learning experiences (Utami & Kurniawati, 2024).

In addition, a process of negotiation of meaning occurred when students discussed the relationship between reproductive hormones, ovulation, fertilization, and implantation before incorporating it into a group mind map. This activity illustrates that students not only passively receive information but also engage in the process of elaborating concepts, clarifying understanding, and evaluating arguments throughout the discussion. Scientific argumentation and collaborative discussion help students elaborate concepts and reconstruct scientific understanding through a deeper process of cognitive reflection (Acar & Azaklı, 2023).

The correlation test results between self-assessment and peer-assessment showed a very strong positive relationship with a correlation coefficient of 0.965. This finding indicates a consistency between students' self-perceptions and peer assessments of their level of participation during the learning process. Students who assessed themselves as active in discussions and mind map preparation were also perceived as active by other group members. This condition strengthens the validity of the student participation data in this study. However, overall, the results of the study indicate that constructive collaborative learning based on collaborative mind maps can create more active, interactive learning and support comprehensive student engagement during biology learning.

Despite these positive findings, implementing the constructive collaborative approach also presented several practical challenges. Classroom observations indicated that the quality of discussions varied across groups, with some groups demonstrating more active exchanges of ideas than others. In several instances, a few students tended to contribute less actively and relied on more dominant peers during collaborative tasks. In addition, developing collaborative mind maps required considerable classroom time because students needed to negotiate ideas, evaluate different perspectives, and organize biological concepts into coherent visual representations. These classroom challenges may partly explain why student participation showed only a moderate positive relationship with critical thinking skills (r_s = 0.392), suggesting that active participation alone is insufficient to maximize higher-order thinking without consistent collaboration and effective instructional facilitation.

The Relationship between Critical Thinking Skills and Student participation

Research shows a positive relationship between critical thinking skills and student participation during learning. These findings indicate that students' active involvement in the learning process contributes to the development of higher-order thinking skills. In constructive collaborative learning, student participation is evident not only in behavioral engagement during discussions but also through cognitive engagement in scientific argumentation, concept elaboration, and idea evaluation during knowledge construction.

This relationship can be explained through collaborative learning mechanisms that enable students to actively construct understanding through social interaction. When students engage in group discussions, they not only convey information but also clarify concepts, defend arguments, evaluate peer opinions, and revise initial understandings based on the results of negotiations over meaning during the learning process (Acar & Azaklı, 2023). These activities encourage cognitive reflection and conceptual conflict, which helps students develop deeper analytical and evaluation skills.

Furthermore, the high levels of agentic and cognitive engagement in the experimental class demonstrate that students play an active role in constructing their own learning experiences. Students who actively express ideas, provide feedback, and guide discussions tend to be more engaged in higher-order thinking processes than those who passively receive information (Ouyang & Dai, 2022). In the collaborative mind map creation process, students also organize concepts, integrate knowledge, and reflect on the relationships between biological concepts, thereby helping to form a deeper and more systematic conceptual structure.

However, the correlation coefficient obtained in this study ($r_s = 0.392$) indicates only a moderate positive relationship, suggesting that student participation contributes to the development of critical thinking skills but is not the only determining factor. This finding is consistent with Hernández-Barco et al. (2021), who reported that student engagement alone does not fully explain students' critical thinking performance because higher-order thinking is also influenced by prior knowledge, learning motivation, instructional quality, and learning experiences.

Likewise, Ouyang and Dai (2022) emphasized that collaborative participation facilitates critical thinking indirectly through meaningful interaction, concept elaboration, reflective dialogue, and knowledge co-construction rather than functioning as a single predictor of critical thinking achievement. Therefore, the moderate correlation observed in this study suggests that student participation is an important pedagogical mechanism for promoting critical thinking; however, its effectiveness depends on the interaction of multiple learner-related and instructional factors during the learning process.

This study provides a theoretical contribution to the development of collaborative learning in biology education, particularly regarding the relationship between student participation and the development of critical thinking skills. The findings indicate that students' active involvement in group discussions, scientific argumentation, concept elaboration, and collaborative mind mapping serve as pedagogical mechanisms that support knowledge construction and the development of higher-order thinking skills. These results reinforce the social constructivist view that knowledge is constructed through social interaction, negotiation of meaning, and collaborative activities throughout the learning process (Vygotsky, 1978).

Furthermore, this study expands the study of student engagement by demonstrating that the dimensions of agentic engagement and cognitive engagement are related to the development of students' critical thinking skills. Student participation is not only

related to behavioral engagement during learning but also functions as a cognitive process that helps students reflect, evaluate ideas, and restructure conceptual understanding through collaborative interactions (Afriani & Zaman, 2026). Thus, this study provides an empirical contribution regarding the role of student participation as part of the knowledge construction process in Biology learning.

Pedagogically, the research results show that a constructive collaborative approach based on collaborative mind maps can be used as an alternative learning strategy for complex and abstract biology materials, such as the human reproductive system. Group discussion activities, scientific argumentation, and the creation of visual representations of concepts help students connect biological concepts more systematically and meaningfully. This learning also provides space for students to more actively express ideas, evaluate understanding, and construct knowledge collaboratively throughout the learning process.

Another implication of this research is the importance of designing learning that is not only oriented towards mastery of the material but also encourages cognitive engagement and active student participation throughout the learning process. Therefore, teachers need to facilitate learning activities that allow students to discuss, elaborate on concepts, and construct visual representations of knowledge collaboratively to make the learning process more active, reflective, and meaningful.

4. Conclusion

A mind map-based constructive collaborative approach effectively enhanced students' critical thinking skills and participation in learning the human reproductive system. Compared with conventional instruction, students in the experimental class demonstrated greater improvements in critical thinking skills and higher levels of agentic and cognitive engagement through collaborative discussions, scientific argumentation, concept elaboration, and mind map construction. A moderate positive relationship between critical thinking skills and student participation further indicates that active engagement contributes to higher-order thinking development, although participation is only one of several factors influencing critical thinking. These findings suggest that integrating collaborative learning with mind mapping promotes a more active, meaningful, and student-centered biology learning environment.

This study was limited to one school, involved intact classes, and was conducted over four instructional sessions. In addition, variations in discussion quality among groups, unequal individual contributions, and the substantial time required for collaborative mind map construction may have influenced the implementation of the approach. These contextual factors should be considered when interpreting the findings and applying the approach in other educational settings. Furthermore, the findings should be generalized with caution because the study focused on a single biology topic and a relatively small sample of students.

Practically, this approach may be applied to other conceptually demanding biology topics, such as the endocrine system, genetics, and ecology, particularly those requiring students to analyze relationships among multiple concepts. Its successful implementation depends on careful instructional planning, including clear collaborative roles, balanced participation, and sufficient time for discussion and concept mapping. Future studies should examine its long-term effectiveness across different schools, larger and more diverse student populations, and a wider range of biology topics to strengthen the generalizability of these findings.

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