ETDC Indonesian Journal of Research and Educational Review
Volume 6, No. 1, 2026, pp 250 - 259
e–ISSN 2809-3682
p–ISSN 2809-7505
https://doi.org/10.51574/ijrer.v6i1.5449

Optimizing Biology Outcomes and Engagement in Human Reproduction via Jigsaw-Mediated Cognitive Load Reduction

Serniati Nababan[1], Endang Sulistyarini Gultom[2]
[1, 2, 3] Department of Biology Education, Universitas Negeri Medan, Indonesia

Article Info

Article history:

Received June 06, 2026
Accepted August 29, 2026
Published September 05, 2026

Keywords:

Biology Education; Jigsaw Cooperative Learning; Human Reproduction; Multi-Dimensional Engagement; ZPD.

ABSTRACT

Addressing sensitive biological concepts, such as human reproduction, frequently generates high cognitive load and socio-emotional anxiety among secondary students, obstructing conceptual mastery and participation. This study evaluated the pedagogical efficacy of Jigsaw cooperative learning in mitigating cognitive load and fostering multi-dimensional engagement among eleventh-grade biology students ($N = 64$). Utilizing an intact cluster quasi-experimental pretest-posttest control group design, two classes were assigned to Jigsaw-mediated peer instruction or conventional direct instruction. Analysis of Covariance (ANCOVA), controlling for baseline variance, revealed a statistically significant treatment effect on posttest achievement, $F(1,61) = 19.45$, $p < .001$, partial $\eta^2 = .242$, with a strong standardized effect size (Cohen's $d = 1.11$). The Jigsaw cohort demonstrated higher adjusted posttest means ($M = 80.82, SD = 8.81$) than the control group ($M = 70.93$, $SD = 8.88$), driven by marked gains in higher-order cognitive domains (C4–C6). Multi-observer fidelity tracking using Diedrich's framework ($\kappa = .88$) confirmed high active engagement across visual, oral, mental, and emotional dimensions (90–95%), though motor activity (80%) was constrained by classroom physical architecture. Grounded in Sweller's Cognitive Load Theory and Vygotsky's Zone of Proximal Development, findings demonstrate that Jigsaw's dual-group architecture redistributes working memory load and alleviates socio-psychological anxiety, offering strong empirical support for peer-assisted learning frameworks in biology curricula.

Corresponding Author:

Serniati Nababan,
Department of Biology Education, Universitas Negeri Medan, Indonesia
Email: serniatinababan462@gmail.com

1. INTRODUCTION

Advancing secondary science education in the twenty-first century necessitates a fundamental paradigm shift from traditional, passive transmission models to active, student-centered instructional designs capable of cultivating higher-order thinking skills (HOTS) and scientific literacy (Freeman et al., 2014; Irdalisa et al., 2024; Kwangmuang et al., 2021). Within high school biology curricula, the human reproductive system represents a foundational yet uniquely challenging domain for pedagogical execution (Fadilah & Nurmawati, 2026; Wahyuni et al., 2019). The biological mechanics of human reproduction involve complex hormonal feedback loops, intricate gametogenesis sequences, and dynamic cellular-level fertilization processes that collectively impose a high intrinsic cognitive load on learners (Castro-Alonso et al., 2024; Putri et al., 2024; Sweller et al., 2019). Compounding this instructional challenge, the topic is deeply intertwined with socio-emotional sensitivity, modesty taboos, and peer discomfort, which frequently induce psychological anxiety and inhibit open classroom dialogue. Consequently, conventional teacher-centered lecture strategies consistently fail to alleviate either cognitive overload or socio-emotional friction, resulting in superficial rote memorization, persistent conceptual misconceptions, and sub-optimal student participation (Hadie et al., 2018; Raheem & Tijani, 2026).

To mitigate these systemic instructional barriers, educational researchers have increasingly advocated for cooperative learning architectures grounded in social constructivism (Lenkauskaitė et al., 2020; Saleem et al., 2021). Among these frameworks, the Jigsaw cooperative model offers a highly structured peer-assisted mechanism that systematically restructures classroom interactions into dual-phase dynamics: specialized "expert groups," where students collaboratively master assigned sub-topics, followed by heterogeneous "home groups," where each student assumes the role of an instructor for their peers (Kebede et al., 2025; Soedimardjono & Pratiwi, 2021). Theoretically, the Jigsaw structure mitigates intrinsic cognitive load by segmenting extensive, multifaceted biological content into manageable information chunks while simultaneously establishing a psychologically safe environment that minimizes embarrassment during sensitive content exchanges (Slavin, 2020). By embedding mutual positive interdependence and individual accountability into the learning process, Jigsaw encourages students to transition from passive information reception to active conceptual synthesis, critical inquiry, and verbal articulation (Gillies, 2016).

Despite extensive scholarship validating cooperative learning across general science domains, significant theoretical and empirical gaps persist within biology education literature. First, existing empirical evaluations of the Jigsaw model predominantly report aggregate achievement scores without elucidating the precise cognitive load reduction mechanisms operating during the acquisition of complex physiological concepts (Kirschner et al., 2018). Second, observational assessments of student classroom behavior frequently rely on generic, unstandardized checklists without embedding them within comprehensive multi-dimensional engagement frameworks—such as active learning classification (Tharwat & Schenck, 2023)—or rigorously controlling for inter-rater reliability and baseline observational parameters. Third, a significant proportion of localized empirical literature evaluates intact classroom implementations using basic descriptive statistics or unadjusted t-tests, neglecting initial baseline variance and potential clustering effects that severely jeopardize internal and external validity.

To address these critical scholarly gaps, this study systematically investigates the pedagogical impact of Jigsaw-type cooperative learning on cognitive achievement and multi-dimensional engagement among eleventh-grade biology students studying human reproduction. Grounded in Cognitive Load Theory (Sweller, 2020) and Vygotsky's Zone of Proximal Development (Xi & Lantolf, 2021), this research constructs a methodologically sound quasi-experimental framework incorporating Analysis of Covariance (ANCOVA) baseline control, psychometric instrument validation, multi-observer fidelity tracking, and standardized effect size estimations. By combining quantitative cognitive measurements with structured behavioral observations, this investigation seeks to elucidate how peer-assisted structures alter cognitive processing and socio-emotional dynamics during the study of taboo-laden biological topics.

Specifically, this study addresses three overarching research questions designed to provide empirical and theoretical clarity to secondary biology pedagogy:

1. RQ1: Does Jigsaw-type cooperative learning significantly enhance cognitive learning outcomes across Bloom's taxonomy levels (C1–C6) compared to conventional direct instruction when controlling for baseline cognitive variance?
2. RQ2: How does Jigsaw peer interaction systematically influence specific operational dimensions of student learning activity according to Diedrich's multi-indicator classification (visual, oral, listening, writing, motor, mental, and emotional)?
3. RQ3: What are the underlying theoretical and pedagogical mechanisms through which Jigsaw-mediated instruction reduces cognitive load and mitigates socio-emotional barriers during instruction on sensitive biological concepts?

2. METHOD

This study utilized a quantitative, quasi-experimental non-equivalent control group pretest-posttest design. Because administrative constraints in secondary school environments preclude the individual random assignment of students without disrupting established class schedules, intact classroom units were utilized. The study population comprised all 126 eleventh-grade science students across five classes at High Secondary School 9 Medan during the 2025/2026 academic year. Purposive sampling was initially applied to identify two intact classes (Class XI-IPA 1 and Class XI-IPA 2) meeting rigorous baseline homogeneity criteria: identical prior biology curricula, equivalent academic tracking, and instruction by the same certified biology educator. Subsequently, cluster-level random assignment (a simple coin toss) designated Class XI-IPA 1 ($n = 32$) as the Experimental Group (Jigsaw cooperative learning) and Class XI-IPA 2 ($n = 32$) as the Control Group (conventional direct instruction), establishing a total sample of $N = 64$ students.

Both instructional conditions were conducted over four standardized 90-minute instructional sessions targeting four core sub-topics of the human reproductive system: (1) Structure and function of male and female reproductive organs, (2) Gametogenesis and hormonal regulation, (3) Menstrual cycle processes and fertilization, and (4) Reproductive system disorders and sexual health. To eliminate teacher bias as a confounding variable, both classes were taught by the same instructor following pre-validated instructional unit plans. Implementation fidelity was systematically monitored by two independent educational researchers using standardized fidelity rubrics (fidelity score > 92%).

In the Experimental Group, instruction followed Aronson's Jigsaw model structured into four sequential phases: (a) Home Group Formation: Heterogeneous 4-member groups were established based on prior academic achievement; (b) Expert Group Investigation: Students separated into specialized expert clusters to analyze assigned sub-topics using structured inquiry worksheets and biological diagrams; (c) Peer Teaching in Home Groups: Experts returned to their home groups to systematically teach their sub-topics, mediate peer questions, and synthesize interrelationships; and (d) Individual Assessment: Students completed individual cognitive evaluations without peer assistance. Conversely, the Control Group received high-quality conventional direct instruction, comprising teacher-led PowerPoint lectures, textbook readings, whole-class question-and-answer sessions, and individual summary exercises covering identical biological content and duration.

Data collection utilized two primary instruments: a Cognitive Learning Outcomes Achievement Test and a Multi-Indicator Learning Activity Observation Sheet.

- Cognitive Achievement Test: A 30-item multiple-choice instrument (5 options) aligned with the revised Bloom's Taxonomy (C1 Remembering to C6 Creating) was constructed. The initial 50-item draft was content-validated by three expert panel reviewers (two biology education professors and one master teacher). Field testing on an independent cohort ($n = 30$) established item validity via Pearson product-moment correlation (39 items exhibited $r_{calculated} > r_{table} = .361$, $p < .05$). Psychometric reliability analysis of the finalized 30-item test yielded a Cronbach's alpha coefficient of $\alpha = .951$, demonstrating exceptional internal consistency. Item difficulty indices ranged from moderate to balanced (difficult = 5, moderate = 40, easy = 5), while discrimination indices confirmed strong item sensitivity (very good = 10, good = 29, fair = 8, poor = 3 discarded).
- Learning Activity Observation Sheet: Student engagement was operationalized using Diedrich's eight-category framework (Sardiman, 2010), encompassing Visual, Oral, Listening, Motor, Writing, Drawing, Mental, and Emotional activities. Each indicator was measured using a structured 4-point Likert observation scale (1 = Inactive to 4 = Highly Active). Observational data were independently gathered by two trained observers across all sessions. Inter-rater reliability was rigorously evaluated using Cohen's Kappa coefficient, achieving $\kappa = .88$ ($p < .001$), indicating near-perfect inter-observer concordance.

Quantitative data were analyzed using IBM SPSS Statistics (v.26.0). Descriptive statistics (means, standard deviations, variances, percentage gains) were calculated for pretest and posttest scores across content sub-topics and cognitive levels. Inferential parametric assumptions were verified: normality was confirmed via Shapiro-Wilk testing ($p > .05$), and variance homogeneity was confirmed via Levene's test ($p > .05$). Pretest baseline equivalence between groups was evaluated using an independent samples t-test.

To test the primary hypothesis while controlling pretest baseline variance in intact classes, Analysis of Covariance (ANCOVA) was executed with pretest score specified as the covariate and posttest score as the dependent variable. Supplementary independent-samples t-test and effect size (Cohen's d) estimations were performed to quantify standardized treatment magnitude. Learning activity scores were analyzed using percentage agreement metrics and categorical performance thresholds.

3. RESULTS AND DISCUSSION

Results

Baseline Equivalence and Psychometric Verification

Prior to experimental intervention, baseline equivalence between the experimental and control groups was statistically evaluated. Shapiro-Wilk tests confirmed normal distribution for both experimental ($W = .968$, $p = .441$) and control pretest scores ($W = .959$, $p = .260$). Levene's test established variance homogeneity across groups, $F(1, 62) = 0.124$, $p = .726$. Independent-samples t-test on pretest scores revealed no statistically significant baseline difference between the Experimental Group ($M = 56.87$, $SD = 9.72$) and Control Group ($M = 56.14$, $SD = 9.43$), $t(62) = 0.305$, $p = .761$, mean difference = 0.73, 95% CI [-4.06, 5.52]. This confirms that both groups possessed equivalent initial cognitive entry behaviors.

Effect of Jigsaw Model on Cognitive Learning Outcomes

Post-intervention descriptive statistics demonstrated substantial cognitive growth in both instructional conditions, with the Experimental Group displaying superior performance overall. Table 1 summarizes the overall descriptive metrics.

Table 1. Descriptive Statistics of Student Learning Outcomes

Statistical Parameter	Exp. Pretest	Exp. Posttest	Ctrl. Pretest	Ctrl. Posttest
Mean Score (M)	56.87	80.82	56.14	70.93
Highest Score	70.00	96.67	70.00	86.67
Lowest Score	36.67	63.33	30.00	46.67
Standard Deviation (SD)	9.72	8.81	9.43	8.88
Variance (S^2)	94.58	70.92	88.96	79.02

As detailed in Table 1, the mean posttest achievement of the Experimental Group reached 80.82 ($SD = 8.81$), representing a 42.1% net improvement over pretest baseline. In contrast, the Control Group achieved a posttest mean of 70.93 ($SD = 8.88$), reflecting a 26.3% net improvement. Granular analysis across biological sub-topics (Table 2) demonstrates consistent experimental superiority.

Table 2. Pretest–Posttest Mean Scores by Biological Content Sub-Topic

Biological Content Indicator	Exp. Pre	Exp. Post	Ctrl. Pre	Ctrl. Post
Structure & Function of Organs	67.86	91.52	65.62	82.59
Gametogenesis & Hormones	57.78	78.52	47.27	62.50
Menstruation & Fertilization	56.64	74.22	61.33	71.09

Biological Content Indicator	Exp. Pre	Exp. Post	Ctrl. Pre	Ctrl. Post
Reproductive Disorders & Health	53.13	81.11	50.89	69.20

Analysis across Cognitive Domain Levels (Bloom's Taxonomy) further illustrates that while basic recall (C1) and comprehension (C2) improved in both groups, higher-order cognitive capabilities—specifically Analyzing (C4), Evaluating (C5), and Creating (C6)—exhibited marked gains in the Jigsaw condition. Cognitive level performance is converted to percentage mastery scores in Table 3 to resolve scaling ambiguity.

Table 3. Cognitive Domain Achievement by Revised Bloom's Taxonomy (% Mastery)

Bloom's Cognitive Level	Exp. Pre (%)	Exp. Post (%)	Ctrl. Pre (%)	Ctrl. Post (%)
C1 – Remembering	60.83%	83.33%	60.83%	70.83%
C2 – Understanding	63.33%	82.67%	63.33%	80.67%
C3 – Applying	65.57%	96.67%	74.00%	87.23%
C4 – Analyzing	55.33%	88.33%	53.33%	67.23%
C5 – Evaluating	66.67%	84.00%	61.33%	77.33%
C6 – Creating	50.83%	77.50%	50.00%	65.00%

To test the primary hypothesis while controlling for baseline pretest scores, an Analysis of Covariance (ANCOVA) was conducted. The main treatment effect was highly significant, $F(1, 61) = 19.45$, $p < .001$, partial $\eta^2 = .242$, confirming that instructional model choice accounted for 24.2% of the variance in posttest achievement independent of prior knowledge. Supplementary independent-samples t-test confirmed $t(61) = 4.410$, $p < .001$, mean difference = 9.64, SE = 2.19. Standardized effect size calculation yielded Cohen's $d = 1.11$ (95% CI [0.58, 1.63]), representing a very large practical treatment impact.

Multi-Dimensional Student Learning Activity

Student engagement in the Experimental Group was evaluated across Diedrich's eight activity indicators using independent dual-observer tracking (Cohen's $\kappa = .88$). Table 4 displays the structured observational results.

Table 4. Observation Results of Experimental-Class Student Learning Activity

Activity Indicator	Raw Score (Max 20)	Mastery (%)	Category	Inter-Rater Agreement
Visual Activity	19.00	95.00%	Very Good	$\kappa = .90$
Oral Activity	19.00	95.00%	Very Good	$\kappa = .86$
Listening Activity	19.00	95.00%	Very Good	$\kappa = .88$
Motor Activity	16.00	80.00%	Good	$\kappa = .85$
Writing Activity	19.00	95.00%	Very Good	$\kappa = .87$
Drawing Activity	18.00	90.00%	Very Good	$\kappa = .89$
Mental Activity	19.00	95.00%	Very Good	$\kappa = .87$
Emotional Activity	19.00	95.00%	Very Good	$\kappa = .90$

As presented in Table 4, seven of eight activity indicators—Visual, Oral, Listening, Writing, Drawing, Mental, and Emotional activities—achieved exceptionally high engagement thresholds (90.00% to 95.00%, 'Very Good' category). Conversely, Motor activity scored 80.00% ('Good' category), reflecting physical spatial constraints of standard classroom furniture during group transitions rather than lack of student interest.

Discussion

Theoretical Mechanisms of Cognitive Load Reduction

The empirical findings demonstrate that Jigsaw cooperative learning significantly outperforms conventional direct instruction in enhancing student achievement in human reproduction biology ($F(1,61) = 19.45$, $p < .001$, Cohen's $d = 1.11$). These results directly align with Cognitive Load Theory (Sweller, 2020; Sweller et al., 2019). Biological topics such as gametogenesis, hormonal regulation, and fertilization possess high intrinsic cognitive load due to complex element interactivity. In conventional direct instruction, students are subjected to simultaneous presentation of dense physiological concepts, which frequently overwhelms working memory capacity (Kirschner et al., 2018).

The Jigsaw architecture mitigates working memory overload through structured information segmenting and collaborative scaffold distribution. During the Expert Group phase, students focus exclusively on mastering one discrete sub-topic, thereby reducing intrinsic load. Subsequent peer teaching in Home Groups obligates students to reorganize, elaborate, and schema-integrate biological information into long-term memory (Fissler et al., 2018; Vives et al., 2025). The substantial performance gains observed in higher-order cognitive domains (C4 Analyzing, C5 Evaluating, and C6 Creating; Table 3) confirm that Jigsaw promotes generative cognitive processing rather than superficial memorization.

Alleviating Socio-Emotional Friction in Sensitive Biological Topics

Human reproduction education frequently encounters socio-psychological barriers, including modesty taboos, peer self-consciousness, and embarrassment (Augustyniak et al., 2023). In traditional teacher-led environments, passive whole-class settings amplify student hesitancy to ask questions or clarify misconceptions regarding reproductive anatomy and sexual health. The Jigsaw model addresses these affective hurdles by establishing small, peer-mediated micro-learning environments.

According to Vygotsky's Social Constructivism and the Zone of Proximal Development (ZPD) (Eun, 2019), peer interaction provides supportive socio-cognitive scaffolding. High emotional and mental activity percentages (95.00%; Table 4) indicate that small-group expert structures foster psychological safety. Peer teaching normalizes scientific terminology, mitigates embarrassment, and encourages active dialogue, enabling students to construct accurate conceptual understandings without socio-emotional discomfort (Slavin, 2014).

Methodological and Practical Limitations

Despite the robust empirical outcomes yielded by this study, several methodological limitations warrant explicit consideration to appropriately contextualize the findings. First, the sample was geographically and institutionally restricted to two intact classes ($N = 64$) within a single urban secondary school, inherently constraining the broader population validity and statistical generalizability of the results. Second, while Analysis of Covariance (ANCOVA) was rigorously deployed to adjust for pre-existing baseline variance on the pretest, the reliance on intact cluster assignment means unobserved classroom-level confounding variables—such as localized peer dynamics or micro-environmental nuances—could not be eliminated.

Furthermore, physical environment constraints and observational scope presented operational boundaries to the investigation. The physical layout of the classrooms imposed spatial limitations on student mobility, which directly accounts for the lower motor activity scores (80.00%) observed during the interventions. Additionally, observational engagement metrics were evaluated strictly within the experimental cohort using a descriptive design. To advance this body of research, subsequent inquiries should incorporate standardized, comparative observational frameworks across both experimental and control conditions to establish a more rigorous comparative baseline.

4. CONCLUSION

This study demonstrates that Jigsaw-type cooperative learning is significantly superior to conventional direct instruction in enhancing cognitive learning outcomes and multi-dimensional engagement among high school students studying the human reproductive system. Controlling for initial baseline variance, Jigsaw instruction produced a statistically significant achievement gain, $F(1, 61) = 19.45$, $p < .001$, partial $\eta^2 = .242$, with a substantial standardized effect size (Cohen's $d = 1.11$). Superior performance was especially evident in higher-order cognitive levels (C4–C6). Furthermore, multi-indicator observational tracking confirmed robust engagement across visual, oral, mental, and emotional dimensions (90–95%).

Theoretically, this research contributes to biology education literature by demonstrating that Jigsaw peer structures mitigate working memory overload (Cognitive Load Theory) and alleviate socio-emotional anxiety inherent in sensitive biological topics through peer-mediated scaffolding (Zone of Proximal Development). Pedagogically, biology educators are encouraged to adopt Jigsaw structures for complex, taboo-laden scientific topics. Future research should expand sample sizes across diverse regional contexts, implement longitudinal retention designs, and incorporate advanced neuro-cognitive or psychophysiological engagement measures.

REFERENCES

Augustyniak, M., Kupka, M., Coticchio, G., Esteves, S., Fincham, A., Lazure, P., & Péloquin, S. (2023). P-577 Understanding how healthcare professionals address the educational and emotional needs of patients seeking fertility care: an assessment of challenges and barriers across eight countries. *Human Reproduction*, *38*(Supplement_1), dead093-123. https://doi.org/10.1093/humrep/dead093.123

Castro-Alonso, J. C., Hidalgo, A. A., & Sweller, J. (2024). Biological evolution and human cognition are analogous information processing systems. *Frontiers in Psychology*, *14*, 1330345. https://doi.org/10.3389/fpsyg.2023.1330345

Eun, B. (2019). The zone of proximal development as an overarching concept: A framework for synthesizing Vygotsky's theories. *Educational philosophy and theory*, *51*(1), 18-30. https://doi.org/10.1080/00131857.2017.1421941

Fadilah, U. N., & Nurmawati, I. (2026). Analisis Miskonsepsi Siswa Berkemampuan Akademik Tinggi Dan Rendah Pada Materi Sistem Reproduksi Manusia Kelas Xi Di Sma Negeri 1 Yosowilangun Lumajang Tahun Ajaran 2025/2026. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, *11*(02), 238-252. https://doi.org/10.23969/jp.v11i02.50236

Fissler, P., Küster, O. C., Laptinskaya, D., Loy, L. S., Von Arnim, C. A., & Kolassa, I. T. (2018). Jigsaw puzzling taps multiple cognitive abilities and is a potential protective factor for cognitive aging. *Frontiers in aging neuroscience*, *10*, 299. https://doi.org/10.3389/fnagi.2018.00299

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Gillies, R. M. (2016). Cooperative learning: Review of research and practice. *Australian Journal of Teacher Education (Online)*, *41*(3), 39-54. https://doi.org/10.14221/ajte.2016v41n3.3

Hadie, S. N. H., Hassan, A., Mohd Ismail, Z. I., Ismail, H. N., Talip, S. B., & Abdul Rahim, A. F. (2018). Empowering students' minds through a cognitive load theory-based lecture model: A metacognitive approach. *Innovations in Education and Teaching International*, *55*(4), 398-407. https://doi.org/10.1080/14703297.2016.1252685

Irdalisa, I., Akbar, B., Fuadi, T. M., Maesaroh, M., & Kartikawati, E. (2024). RICOSRE model with question formulation technique (QFT): Enhancing students' higher order thinking skills (HOTS) and science literacy. *Jurnal Penelitian Pendidikan IPA*, *10*(3), 1175-1178. https://doi.org/10.29303/jppipa.v10i3.6764

Kebede, Y. A., Zema, F. K., Geletu, G. M., & Zinabu, S. A. (2025). Cooperative learning instructional approach and student's biology achievement: A quasi-experimental evaluation of jigsaw cooperative learning model in secondary schools in Gedeo Zone, South Ethiopia. *Sage Open*, *15*(1), 21582440251318883. https://doi.org/10.1177/21582440251318883

Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano R, J. (2018). From cognitive load theory to collaborative cognitive load theory. *International journal of computer-supported collaborative learning*, *13*(2), 213-233. https://doi.org/10.1080/00461520.2018.1480353

Kwangmuang, P., Jarutkamolpong, S., Sangboonraung, W., & Daungtod, S. (2021). The development of learning innovation to enhance higher order thinking skills for students in Thailand junior high schools. *Heliyon*, *7*(6). https://doi.org/10.1016/j.heliyon.2021.e07309

Lenkauskaitė, J., Colomer, J., & Bubnys, R. (2020). Students' social construction of knowledge through cooperative learning. *Sustainability*, *12*(22), 9606. https://doi.org/10.3390/su12229606

Putri, M. D., Rahmat, A., & Sanjaya, Y. (2024). The Use of Chunking Technique Combined with the Writing Is Thinking Technique to Control Students' Cognitive Load When Learning About the Human Reproductive System. *KnE Social Sciences*, 83-90. https://doi.org/10.70232/jrese.v3i2.59

Raheem, I. S., & Tijani, J. K. (2026). Technological pedagogical content knowledge and conventional lecture method: Comparative effects on biology learning outcomes. *Journal of Research in Environmental and Science Education*, *3*(2), 151-163. https://doi.org/10.18502/kss.v9i8.15489

Saleem, A., Kausar, H., & Deeba, F. (2021). Social constructivism: A new paradigm in teaching and learning environment. *Perennial journal of history*, *2*(2), 403-421. https://doi.org/10.52700/pjh.v2i2.86

Slavin, R. E. (2014). Aprendizaje cooperativo y rendimiento académico:¿ por qué funciona el trabajo grupal?. *Anales de psicología*, *30*(3), 785-791. https://doi.org/10.6018/analesps.30.3.201201

Slavin, R. E. (2020). How evidence-based reform will transform research and practice in education. *Educational psychologist*, *55*(1), 21-31. https://doi.org/10.1080/00461520.2019.1611432

Soedimardjono, F. P., & Pratiwi, P. (2021). Cooperative learning model with jigsaw type improves students' sciences process skills and learning outcomes. *JPI (Jurnal Pendidikan Indonesia)*, *10*(1), 172-179. https://ejournal.undiksha.ac.id/index.php/JPI/article/view/25203

Sweller, J. (2020). Cognitive load theory and educational technology: J. Sweller. *Educational technology research and development*, *68*(1), 1-16. https://doi.org/10.1007/s11423-019-09701-3

Sweller, J., Van Merriënboer, J. J., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational psychology review*, *31*(2), 261-292. https://doi.org/10.1007/s10648-019-09465-5

Tharwat, A., & Schenck, W. (2023). A survey on active learning: State-of-the-art, practical challenges and research directions. *Mathematics*, *11*(4), 820. https://doi.org/10.3390/math11040820

Vives, E., Bressan, M., Poletti, C., Caroti, D., Butera, F., Huguet, P., ... & Régner, I. (2025). Uncovering the relationship between working memory and performance in the Jigsaw classroom. *PloS one*, *20*(3), e0319495. https://doi.org/10.1371/journal.pone.0319495

Wahyuni, N., Suwono, H., & Lestari, U. (2019). Learning difficulties of high school students in understanding the material of human reproductive systems triggering misconceptions. *Jurnal Pendidikan Sains Universitas Negeri Malang*, *7*(4). https://doi.org/10.17977/jps.v7i4.12524

Xi, J., & Lantolf, J. P. (2021). Scaffolding and the zone of proximal development: A problematic relationship. *Journal for the Theory of Social Behaviour*, *51*(1), 25-48. https://doi.org/10.1111/jtsb.12260