Integrating 3C3R Design Problem and Four-Component Instructional Design (4C/ID) into Problem-Based Learning: Addressing Students' Cognitive Load in Biology Education

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Abstract. Problem-Based Learning (PBL) is widely adopted in biology education; however, its implementation frequently generates excessive cognitive load for students, particularly when instructional scenarios are poorly structured or when teachers lack expertise in designing contextually appropriate problems. This study presents the development and validation of a PBL model integrated with 3C3R Design Problem (Content, Context, Connection, Research, Reasoning, Reflection) and Four-Component Instructional Design (4C/ID) frameworks, specifically designed to reduce students' cognitive load in junior high school (SMP) biology classes in Sambas Regency, West Kalimantan, Indonesia. A Research and Development (R&D) approach was employed using the Hannafin & Peck model, encompassing three phases: needs analysis, design, and development. The effectiveness of the integrated model was tested using a quasi-experimental non-equivalent pretest-posttest control group design involving 612 SMP students (n_1 = 306 experimental; n_2 = 306 control) across 20 schools. Expert validation yielded an overall validity score of 4.52 (Highly Valid), and practicality ratings from teachers (M = 4.40) and students (M = 4.29) confirmed classroom feasibility. ANCOVA results demonstrated that the integrated model produced significantly lower intrinsic and extraneous cognitive load and significantly higher germane cognitive load than conventional PBL, with large effect sizes (η^2p = 0.31–0.57). These findings underscore the importance of structured instructional design frameworks in mitigating cognitive overload in complex, problems-based science learning environments.
Keywords: 3C3R Design Problem, Biology Education, Cognitive Load, Four-Component Instructional Design (4C/ID)

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1. Introduction

Problem-Based Learning (PBL) has become one of the most widely adopted active learning strategies in science education, particularly in biology, owing to its capacity to foster critical thinking, inquiry skills, and meaningful understanding of complex concepts (Funa & Prudente, 2021; Trullàs et al., 2022). Unlike traditional teacher-centered instruction, PBL situates students in authentic, ill-structured problems that necessitate collaborative investigation, hypothesis generation, and evidence-based reasoning (Moallem et al., 2019). These characteristics make PBL particularly suitable for biology education, where students are routinely expected to navigate abstract and interrelated concepts such as ecosystems, cellular mechanisms, and human physiology (Junco & Nabua, 2023; Trisianawati & Manisa, 2023).

Despite its theoretical promise, the effective implementation of PBL in real classroom settings particularly at the junior secondary level faces considerable challenges. A primary concern is the tendency for PBL to generate excessive cognitive load among students. Cognitive Load Theory (CLT), originally proposed by Sweller (2004) and elaborated by Paas and Van Merrienboer (2020), posits that the human working memory has a finite capacity to process new information simultaneously. When instructional materials are poorly organized or insufficiently scaffolded, students may experience cognitive overload, resulting in diminished learning efficiency and reduced academic engagement (Janssen & Kirschner, 2020; Sweller et al., 2019). In the context of PBL, cognitive overload frequently arises when students are uncertain about problem-solving steps, when learning tasks lack adequate gradation, or when teachers lack skills to design cognitively manageable problem scenarios (Ghufron & Ermawati, 2018; Merritt et al., 2017).

A preliminary study conducted as part of the present research surveyed 150 junior high school students (Grades VII and VIII) across three schools in Sambas Regency using the Cognitive Load Measurement (CLM) questionnaire (Paas et al., 1994). Findings revealed substantially elevated intrinsic load ($M = 6.82$, $SD = 1.24$) and extraneous load ($M = 7.15$, $SD = 1.18$), both well above the scale midpoint, while germane load was relatively low ($M = 3.47$, $SD = 1.32$). These results indicate that cognitive demands of existing PBL implementation were dominated by content complexity and instructional inefficiency rather than productive schema formation. Complementary evidence from related studies (Pratama & Zilhakim, 2022; Nadila & Sukma, 2020) further documented that PBL implementation failed to produce significant gains in students' science literacy, confirming a systemic need for more carefully designed instructional approaches.

Two instructional design frameworks have demonstrated particular relevance. First, the 3C3R Design Problem framework Content, Context, Connection, Research, Reasoning, and Reflection provides a systematic structure for designing problems that are contextually meaningful, cognitively appropriate, and conducive to deep understanding (Malik et al., 2020). Studies confirm that 3C3R enables students to connect biological concepts to their daily experiences, thereby reducing unnecessary cognitive effort (Burhanudin et al., 2018). Second, the Four-Component Instructional Design (4C/ID) model (Van Merrienboer et al., 2002) offers a blueprint for designing complex learning tasks with progressive scaffolding through four components: Learning Tasks, Supportive Information, Procedural Information, and Part-Task Practice explicitly intended to reduce cognitive overload by organizing experiences from simple to complex, aligned with students' evolving competence.

Despite the demonstrated efficacy of each framework individually, no prior study has systematically integrated 3C3R Design Problem and 4C/ID within a PBL context to specifically address cognitive load in biology education. This represents a critical gap in the instructional design literature. The present study therefore aims to develop, validate, and test the effectiveness of a PBL model integrating the 3C3R Design Problem and 4C/ID frameworks to reduce students' cognitive load in junior high school biology education in Sambas Regency, West Kalimantan. Specifically, three research questions are addressed: (1) How can these frameworks be systematically integrated into PBL to create a cognitively supportive model? (2) What factors influence its success in reducing cognitive load? (3) How effective is the integrated model compared to conventional PBL? The novelty lies in the simultaneous integration of two complementary instructional design frameworks within a PBL environment, directly responding to Indonesia's SDG 4.7 commitment to quality and innovative education.

2. Method

2.1. Research Design

This study employed a Research and Development (R&D) methodology, adopting the Hannafin and Peck (Taylor, 2004) model as its design framework. The Hannafin and Peck model consists of three sequential phases needs analysis, design, and development, each accompanied by systematic evaluation and revision processes. Following the development phases, the effectiveness of the finalized model was tested using a quasi-experimental non-equivalent pretest-posttest control group design (Cohen et al., 2002), which allowed comparison of cognitive load outcomes between students receiving the integrated PBL-3C3R-4C/ID model (experimental group) and those receiving conventional PBL (control group).

3.2. Participants

The study population comprised junior high school (SMP) students across Sambas Regency, West Kalimantan, Indonesia a region encompassing 130 public and private SMP institutions. Sampling was conducted using cluster random sampling, where by 20 schools distributed across 19 sub-districts (kecamatan) within Sambas Regency were randomly selected. Ten schools were randomly assigned to the experimental condition and ten to the control condition. A total of 612 students participated in the effectiveness testing phase (experimental: n = 306; control: n = 306), with an average class size of approximately 31 students per school. Biology teachers from selected schools attended structured training workshops on the integrated model's syntax and implementation procedures. Additionally, 150 students from three schools participated in the preliminary needs analysis phase.

3.3. Instruments

3.3.1. Cognitive Load Measurement Questionnaire

Cognitive load was measured using the CLM questionnaire developed by Paas et al. (1994), which has been widely used in educational research contexts to assess subjective ratings of cognitive effort and load. The instrument measures three cognitive load components: intrinsic load (perceived difficulty of learning content), extraneous load (perceived difficulty arising from instructional design), and germane load (perceived mental effort invested in schema formation). Items were rated on a 9-point Likert scale (1=very, very low mental effort to 9 = very, very high mental effort). The instrument was adapted for the biology learning context and validated by expert reviewers prior to use.

3.3.2. Model Validity Questionnaire

The validity of the integrated PBL-3C3R-4C/ID model was assessed using expert validation questionnaires developed specifically for this study. Expert panels comprised five validators: two learning model specialists and three biology content and pedagogy experts. Validators evaluated model components on dimensions of theoretical coherence, content alignment, instructional feasibility, and syntactic clarity using a 5-point Likert scale. Validity was classified as highly valid (≥ 4.21), valid (3.41–4.20), moderately valid (2.61–3.40), or invalid (< 2.61).

3.3.3. Practicality Assessment Questionnaire

Practicality was evaluated through structured questionnaires administered to biology teachers (assessing instruction clarity, time feasibility, and curriculum alignment) and students (assessing comprehensibility, engagement quality, and perceived instructional support). Positive practicality was defined as mean scores ≥ 3.6 on a 5-point scale with ≥ 80% of respondents rating ≥ 4.

3.3.4. Biology Achievement Test

A criterion-referenced biology achievement test was developed to assess students' conceptual understanding at multiple Bloom's Taxonomy levels (comprehension through evaluation). The test was validated for content validity by biology education experts and piloted for reliability prior to main data collection.

3.4. Development Procedure

Phase 1: Needs Analysis. This phase comprised: (1) a preliminary cognitive load survey of 150 students across three schools; (2) systematic literature review of PBL, CLT, 3C3R, and 4C/ID; and (3) structured interviews and classroom observations with biology teachers to identify instructional challenges. Findings directly informed the design specifications of the integrated model.

Phase 2: Design. This phase involved the development of Prototype 1 of the integrated PBL-3C3R-4C/ID model, encompassing model syntax, 3C3R-based learning task designs, 4C/ID task sequencing, supportive and procedural information packages, and embedded assessment instruments. The prototype was developed collaboratively through FGDs with stakeholders and MGMP IPA Sambas Regency representatives. Expert validation was conducted, yielding Prototype 2 after revision cycles.

Phase 3: Development. Prototype 2 underwent small-scale trial implementation at one school involving 2 biology teachers and 32 students, followed by teacher training workshops for MGMP biology teachers. Based on trial findings and participant feedback, a revised Prototype 3 was developed and implemented in the large-scale effectiveness trial across 20 schools.

3.5. Data Analysis

Validity data were analyzed using Content Validity Ratio (CVR) and Content Validity Index (CVI) procedures; validity was classified as valid when mean expert ratings exceeded 3.6 on a 5-point scale. Practicality data were analyzed using descriptive statistics with positive practicality defined as mean scores ≥ 3.6 and $\geq 80\%$ positive ratings. Pre-test equivalence between groups was confirmed using independent samples t-tests. For the effectiveness analysis, cognitive load scores were compared between groups using ANCOVA, controlling for pre-test cognitive load scores. Adapted N-Gain scores were computed for each cognitive load component: for intrinsic and extraneous load (where lower post-test scores indicate improvement), the formula $g = (Pre - Post)/(Pre - 1)$ was applied; for germane load (where higher post-test scores indicate improvement), the formula $g = (Post - Pre)/(9 - Pre)$ was applied, following Hake's (1998) framework as adapted for cognitive load reduction research. Effect sizes were calculated using partial eta squared (η^2p) and Cohen's d. All statistical analyses were performed using SPSS 27.0, with $\alpha = 0.05$.

3. Results and Discussion

3.1. Needs Analysis

The preliminary needs analysis confirmed the presence of significant cognitive load among junior high school students in Sambas Regency during biology PBL instruction. Across the three schools surveyed ($n = 150$), mean scores on the CLM questionnaire indicated that intrinsic load ($M = 6.82$, $SD = 1.24$) and extraneous load ($M = 7.15$, $SD = 1.18$) were both substantially elevated above the scale midpoint of 5.0, while germane load was relatively low ($M = 3.47$, $SD = 1.32$). These results suggest that the cognitive demands of existing PBL implementation were dominated by content complexity and instructional design inefficiency rather than productive schema formation. Teacher interviews revealed that the majority of biology teachers lacked structured guidance for designing PBL problem scenarios and reported uncertainty in calibrating task difficulty to student competence levels, confirming the practical rationale for developing an integrated instructional model.

3.2. Validity of the Integrated PBL-3C3R-4C/ID Model

Table 1 presents the validity assessment results for the integrated PBL-3C3R-4C/ID model as evaluated by five expert validators.

Table 1. Expert Validity Assessment Results for the Integrated PBL-3C3R-4C/ID Model

Validation Aspect	Mean Score	Category	Decision
Theoretical Basis & Coherence	4.52	Highly Valid	Valid
Syntax & Instructional Sequence	4.45	Highly Valid	Valid
Problem Design (3C3R Alignment)	4.61	Highly Valid	Valid
Task Scaffolding (4C/ID Alignment)	4.48	Highly Valid	Valid
Cognitive Load Management	4.55	Highly Valid	Valid
Overall Validity	4.52	Highly Valid	Valid

Note. Validity category thresholds (5-point scale): Highly Valid ≥ 4.21; Valid ≥ 3.41; Moderately Valid ≥ 2.61; Invalid < 2.61. N = 5 expert validators.

All six evaluated dimensions of the integrated model achieved Highly Valid ratings (all scores ≥ 4.45), with an overall validity score of M = 4.52. The highest validity score was assigned to the Problem Design (3C3R Alignment) dimension (M = 4.61), indicating that expert validators found the operationalization of the 3C3R framework within the PBL problem design guidelines to be particularly well-grounded and practically coherent. The Syntax & Instructional Sequence dimension received the minimum score (M = 4.45), which nonetheless comfortably exceeded the Highly Valid threshold. Validators specifically commended the model's explicit scaffolding of cognitive load management within problem design steps and the clear articulation of task progression principles derived from the 4C/ID framework. Minor revisions recommended by validators including the addition of worked examples in the supportive information component and clarification of rubric language were incorporated into Prototype 2 prior to practicality testing.

3.3. Practicality of the Model

Following small-scale trial implementation at one school (2 biology teachers and 32 students), practicality questionnaires were administered to both teacher and student participants. Teacher practicality scores (M = 4.40) were uniformly positive, with 100% of teachers rating the model positively (≥ 4 on the 5-point scale). Teachers specifically noted that the 3C3R problem design templates provided clear, actionable guidance that substantially reduced the cognitive burden of scenario design compared to conventional PBL preparation. Students in the pilot trial reported strong practicality (M = 4.23, SD = 0.48), with 84.4% providing positive ratings. Following model revision based on pilot feedback, the large-scale trial implementation across 306 experimental students yielded similarly strong practicality ratings (M = 4.29, SD = 0.46), with 87.9% of students rating the model positively. Students consistently noted that the 4C/ID-based progressive task structure made complex biology topics feel more approachable and systematically organized. These findings confirm the model's practical viability for implementation across diverse SMP classroom contexts within Sambas Regency.

3.4. Effectiveness of the Model: Cognitive Load Outcomes

Prior to effectiveness testing, independent samples t-tests confirmed the equivalence of the experimental and control groups at pre-test across all three cognitive load components: intrinsic load, $t(610) = -0.52$, $p = .605$; extraneous load, $t(610) = 0.31$, $p = .755$; germane load, $t(610) = 0.19$, $p = .847$. These non-significant differences indicate that the two groups were statistically equivalent at baseline, supporting the validity of subsequent ANCOVA comparisons.

Table 2 presents descriptive statistics for cognitive load scores across experimental and control groups at pre-test and post-test timepoints, together with adapted N-Gain scores.

Table 2. Descriptive Statistics of Cognitive Load Scores by Group and Timepoint

Variable	Group	Pre-test M (SD)	Post-test M (SD)	N-Gain (Category)
Intrinsic Cognitive Load	Experimental	6.84 (1.21)	5.07 (1.18)	0.30 (Medium)
	Control	6.89 (1.18)	6.51 (1.24)	0.06 (Low)
Extraneous Cognitive Load	Experimental	7.11 (1.16)	4.42 (1.13)	0.44 (Medium)
	Control	7.08 (1.22)	6.84 (1.29)	0.04 (Low)
Germane Cognitive Load	Experimental	3.51 (1.29)	5.97 (1.16)	0.45 (Medium)
	Control	3.49 (1.27)	3.74 (1.22)	0.05 (Low)

Note. M = Mean; SD = Standard Deviation. N-Gain for Intrinsic and Extraneous Cognitive Load (CL): $g = (Pre - Post)/(Pre - 1)$; N-Gain for Germane CL: $g = (Post - Pre)/(9 - Pre)$. N-Gain categories: High ≥ 0.70; Medium 0.30–0.69; Low < 0.30 (Hake, 1998, adapted).

As shown in Table 2, the experimental group demonstrated meaningful reductions in both intrinsic and extraneous cognitive load from pre-test to post-test, alongside a substantial increase in germane cognitive load. In contrast, the control group showed only minimal change across all three components. N-Gain scores for the experimental group fell in the medium range for all three cognitive load components (intrinsic: $g = 0.30$; extraneous: $g = 0.44$; germane: $g = 0.45$), while N-Gain scores for the control group were consistently low (0.04–0.06), indicating negligible change in cognitive load profiles under conventional PBL.

ANCOVA results, controlling for pre-test cognitive load as a covariate, are presented in Table 3 for all three cognitive load components.

Table 3. ANCOVA Results for Post-test Cognitive Load Scores by Component (Controlling for Pre-test)

CL Component	Source	SS	df	MS	F	p	η^2p
Intrinsic CL	Pre-test (Covariate)	197.41	1	197.41	172.67	< .001	—
	Group (Treatment)	317.26	1	317.26	277.51	< .001	**0.313**
	Error	696.24	609	1.143	—	—	—
	Total	1210.91	611	—	—	—	—
Extraneous CL	Pre-test (Covariate)	224.25	1	224.25	203.00	< .001	—
	Group (Treatment)	896.03	1	896.03	811.12	< .001	**0.571**
	Error	672.75	609	1.105	—	—	—
	Total	1793.03	611	—	—	—	—
Germane CL	Pre-test (Covariate)	175.03	1	175.03	154.64	< .001	—
	Group (Treatment)	760.85	1	760.85	672.18	< .001	**0.525**
	Error	689.34	609	1.132	—	—	—
	Total	1625.22	611	—	—	—	—

Note. SS = Sum of Squares; MS = Mean Square; η^2p = Partial Eta Squared. df_error = 609 for all components. Effect size benchmarks: small ($\eta^2p = .01$), medium ($\eta^2p = .06$), large ($\eta^2p = .14$). All Group (Treatment) effects are significant at $p < .001$.

The ANCOVA results confirmed that the group factor (treatment vs. control) exerted a statistically significant effect on post-test scores for all three cognitive load components, after controlling for pre-test cognitive load. The treatment effect was most pronounced for extraneous cognitive load ($F(1,609) = 811.12$, $p < .001$, $\eta^2p = 0.571$), indicating that the integrated model's instructional design features particularly the 3C3R problem design scaffolding dramatically reduced the unnecessary processing demands that students in the control group continued to experience under conventional PBL. The effect on germane cognitive load was also substantial ($F(1,609) = 672.18$, $p < .001$, $\eta^2p = 0.525$), reflecting a significant increase in productive schema-building activity among experimental students. The effect on intrinsic cognitive load, while smaller in magnitude, was nonetheless large by conventional standards ($F(1,609) = 277.51$, $p < .001$, $\eta^2p = 0.313$), suggesting that the 4C/ID-based task sequencing also helped students manage the inherent complexity of biological content more effectively. Cohen's d values for the three outcomes were 1.19 (intrinsic), 2.00 (extraneous), and 1.87 (germane), all substantially exceeding the conventional large-effect threshold of 0.80. Pre-test covariate effects were significant for all components, confirming that controlling for baseline cognitive load was a methodologically appropriate and necessary step.

4. Conclusion

This study developed, validated, and tested the effectiveness of an integrated PBL-3C3R Design Problem-4C/ID instructional model for reducing cognitive load among junior high school biology students. The model achieved Highly Valid expert ratings across all dimensions (overall M = 4.52), confirmed strong practicality from both teachers (M = 4.40; 100% positive) and students (M = 4.29; 87.9% positive), and demonstrated statistically significant and large-effect superiority over conventional PBL in reducing intrinsic and extraneous cognitive load while increasing germane cognitive load ($\eta^2p = 0.31–0.57$). These findings establish the integrated model as a theoretically coherent, practically viable, and empirically effective instructional design innovation for biology education in Indonesian junior high school settings.

The theoretical contribution lies in the empirical extension of Cognitive Load Theory to PBL-based science education through the simultaneous operationalization of two complementary design frameworks. For educational practice, the results provide actionable guidance for biology teachers, curriculum developers, and school administrators seeking to implement PBL in cognitively supportive ways. The structured problem design templates and task sequencing guides developed as part of this model offer practical tools adoptable with modest professional development investment, directly addressing the teacher competence gap documented in the preliminary study.

Several limitations should be acknowledged. The sample was geographically constrained to Sambas Regency, limiting generalizability. The study's reliance on self-report cognitive load measures may introduce response bias; future studies should complement these with behavioral indicators. The quasi-experimental design precludes fully causal attributions. Future research should explore model applicability across different biology topics and educational levels, examine long-term sustainability of effects, and investigate moderating factors such as teacher experience and school resource availability.

As Indonesia advances toward its educational goals under SDG 4.7 and the Asta Cita national vision, the need for evidence-based instructional innovations that balance academic rigor with cognitive accessibility has never been more pressing. The integrated PBL-3C3R-4C/ID model represents a meaningful step toward realizing those goals in biology education and in science education more broadly.

References

Burhanudin, R., Subarkah, C. Z., & Sari, S. (2018). Penerapan model pembelajaran *Content Context Connection Researching Reasoning Reflecting* (3C3R) untuk mengembangkan keterampilan generik sains siswa pada konsep koloid. *Jurnal Tadris Kimiya*, *3*(1), 11–21. https://doi.org/10.15575/jtk.v3i1.2595

Cohen, L., Manion, L., & Morrison, K. (2000). *Research methods in education* (5th ed.). Routledge. https://doi.org/10.4324/9780203224342
Catatan: DOI ini tercatat untuk edisi ke-5 tahun 2000; jika naskah Bapak wajib mengikuti sumber fisik tahun 2002, tahun dapat disesuaikan kembali.

Funa, A. A., & Prudente, M. S. (2021). Effectiveness of problem-based learning on secondary students' achievement in science: A meta-analysis. *International Journal of Instruction*, *14*(4), 69–84. https://doi.org/10.29333/iji.2021.1445a

Ghufron, M. A., & Ermawati, S. (2018). The strengths and weaknesses of cooperative learning and problem-based learning in EFL writing class: Teachers' and students' perspectives. *International Journal of Instruction*, *11*(4), 657–672. https://doi.org/10.12973/iji.2018.11441a

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Janssen, J., & Kirschner, P. A. (2020). Applying collaborative cognitive load theory to computer-supported collaborative learning: Towards a research agenda. *Educational Technology Research and Development*, *68*, 783–805. https://doi.org/10.1007/s11423-019-09729-5

Jordan, J., Wagner, J., Manthey, D. E., Wolff, M., Santen, S., & Cico, S. J. (2020). Optimizing lectures from a cognitive load perspective. *AEM Education and Training*, *4*(3), 306–312. https://doi.org/10.1002/aet2.10389

Junco, M. A., & Nabua, E. (2023). The academic performance of grade-11 biology on modular distance learning: Basis for instructional material development. *International Journal of Science Education and Teaching*, *2*(2), 87–105. https://doi.org/10.14456/ijset.2023.7

Kardoyo, Nurkhin, A., Muhsin, & Pramusinto, H. (2020). Problem-based learning strategy: Its impact on students' critical and creative thinking skills. *European Journal of Educational Research*, *9*(3), 1141–1150. https://doi.org/10.12973/eu-jer.9.3.1141

Magaji, A. (2021). Promoting problem-solving skills among secondary science students through problem-based learning. *International Journal of Instruction*, *14*(4), 549–566. https://doi.org/10.29333/iji.2021.14432a

Malik, A., Yuliani, Y., Rochman, C., Zakwandi, R., Ismail, A., & Ubaidillah, M. (2020). Optimizing students' critical thinking skills related to heat topics through the model of content, context, connection, researching, reasoning, reflecting (3C3R). *Journal of Physics: Conference Series*, *1521*(2), Article 022001. https://doi.org/10.1088/1742-6596/1521/2/022001

Merritt, J., Lee, M. Y., Rillero, P., & Kinach, B. M. (2017). Problem-based learning in K–8 mathematics and science education: A literature review. *Interdisciplinary Journal of Problem-Based Learning*, *11*(2), Article 3. https://doi.org/10.7771/1541-5015.1674

Nadila, N., & Sukma, E. (2020). Penggunaan model *Problem Based Learning* (PBL) pada pembelajaran tematik terpadu di kelas IV SDN 19 Koto Taratak Kabupaten Pesisir Selatan. *Jurnal Pendidikan Tambusai*, *4*(3), 2508–2517. https://doi.org/10.31004/jptam.v4i3.737

Paas, F. G. W. C., van Merriënboer, J. J. G., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills*, *79*(1), 419–430. https://doi.org/10.2466/pms.1994.79.1.419

Paas, F., & van Merriënboer, J. J. G. (2020). Cognitive-load theory: Methods to manage working memory load in the learning of complex tasks. *Current Directions in Psychological Science, 29*(4), 394–398. https://doi.org/10.1177/0963721420922183

Pratama, M. A., & Zilhakim, R. (2022). Pengaruh model pembelajaran *Problem Based Learning* berbasis *blended learning* terhadap literasi sains siswa di MTsN 1 Bengkulu Selatan. *Jurnal Jendela Pendidikan, 2*(1), 54–60. https://doi.org/10.57008/jjp.v2i01.128

Savery, J. R. (2019). Comparative pedagogical models of problem-based learning. In M. Moallem, W. Hung, & N. Dabbagh (Eds.), *The Wiley handbook of problem-based learning* (pp. 81–104). Wiley. https://doi.org/10.1002/9781119173243.ch4

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science, 32*, 9–31. https://doi.org/10.1023/B:TRUC.0000021808.72598.4d

Sweller, J., van Merriënboer, J. J. G., & 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

Taylor, L. (2004). Educational theories and instructional design models: Their place in simulation. *Nursing Education Research, Southern Health*, 1–6.
Catatan: DOI tidak ditemukan pada metadata terbuka yang tersedia.

Trisianawati, E., Dafrita, I. E., & Darmawan, H. (2019). A development of biodiversity module based on socioscientific issues and local potential for department students of IKIP PGRI Pontianak. *Indonesian Journal of Biology Education, 2*(2), 8–13. https://doi.org/10.31002/ijobe.v2i2.2005

Trisianawati, E., & Darmawan, H. (2016). Peranan dosen dalam pembelajaran berbasis masalah berorientasi pada peningkatan keterampilan proses sains mahasiswa. *Jurnal Edukasi Matematika dan Sains, 4*(2), 102–107.
Catatan: DOI tidak ditemukan pada laman Garuda/jurnal yang tersedia.

Trisianawati, E., & Manisa, T. (2023). The ability of critical thinking and problem solving prospective biology teacher to solve biological Olympiad questions. *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan, 5*(1), 1–7. https://doi.org/10.20527/bino.v5i1.15004

Trullàs, J. C., Blay, C., Sarri, E., & Pujol, R. (2022). Effectiveness of problem-based learning methodology in undergraduate medical education: A scoping review. *BMC Medical Education, 22*, Article 104. https://doi.org/10.1186/s12909-022-03154-8

van Merriënboer, J. J. G., Clark, R. E., & de Croock, M. B. M. (2002). Blueprints for complex learning: The 4C/ID-model. *Educational Technology Research and Development, 50*(2), 39–61. https://doi.org/10.1007/BF02504993