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DEVELOPMENT OF SCRATCH-BASED SELF-PACED INTERACTIVE SCIENCE LEARNING MEDIA ON THE BUTTERFLY LIFE CYCLE FOR FOURTH-GRADE STUDENTS

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ABSTRACT
Elementary science learning is often reported to offer limited interactive visualization, which can reduce students' attention and engagement. This study aims to design, develop, and evaluate a Scratch-based self-paced Interactive Learning Media (MPI) on the butterfly life cycle for fourth-grade students at SDN Nggembe. To limit extraneous cognitive load, the media applies self-paced learning through static illustrations, concise instructional text, and user-controlled navigation buttons (Play, Next, Back, and Menu) that prevent automatic slide transitions. The study followed a researcher-designed four-stage development framework consisting of planning, design (interaction flow and flowchart), implementation (block-based coding), and testing (functional testing and limited field testing). The resulting media comprises a start screen, main menu, topic selection, content screens, and a quiz module with automated instant feedback, in which each correct answer adds 25 points to the score. All predefined functional components were implemented and operated as designed. During limited field testing at SDN Nggembe, students reported that the self-paced navigation helped them follow the metamorphosis sequence comfortably and showed enthusiasm for the media. Learning gains and cognitive load were not measured directly and should be examined in further studies.
Keywords *: Interactive Learning Media; Scratch; Metamorphosis; Self-Paced Learning; Cognitive Load.*

1. Introduction

The learning of Natural Sciences (IPA) at the elementary school level, particularly the concept of the butterfly life cycle for fourth-grade students, requires clear, concrete, and engaging visualization. Low learning outcomes in elementary science remain a challenge that calls for more innovative learning approaches, and interactive media such as educational games have been proposed as a way to attract students' attention and increase their engagement and motivation in science lessons (Sari & Rohmani, 2024). In a science context, Scratch activities were also reported to help fourth-grade gifted students comprehend science material and to deepen their interest in science lessons (Bozan et al., 2025).

Scratch is a free, visual, block-based programming environment developed at the MIT Media Lab that allows educators to build interactive stories, animations, and quizzes without writing text-based code (Resnick et al., 2009). Scratch-based media have been developed for elementary classrooms and rated as feasible by experts, teachers, and students, for example for environmental conservation material in grade V (Maola & Irianto, 2023) and for fractions in grade IV (Kartika & Trimurtini, 2026). Scratch has also been used as a meaningful environment for elementary students to construct mathematical concepts (Anabousy et al., 2023), and visual programming with Scratch has been reported to be feasible in elementary education, with benefits related to motivation and interest (Sáez-López et al., 2023).

However, the studies reviewed above mainly report feasibility, expert validation, or student perceptions, and they do not explicitly describe how the pacing of the interface is designed to manage the cognitive load of young learners. This matters because presentations that contain unnecessary or fast-changing elements may increase extraneous cognitive load (Mayer, 2021; Sweller, 2020). Meta-analytic evidence suggests that the benefit of good multimedia design is larger in system-paced environments (e.g., lectures) than in self-paced ones (e.g., websites) (Noetel et al., 2022), and that presenting content in segments reduces overall cognitive load and

improves retention and transfer (Rey et al., 2019). The research gap can therefore be summarized as follows. Previous Scratch-based media studies in elementary schools (Kartika & Trimurtini, 2026; Maola & Irianto, 2023) focused on feasibility and student responses; they gave limited attention to the explicit design of learner-controlled pacing, and none of the studies reviewed here addressed the butterfly life cycle. What is needed is a science medium whose pacing is deliberately controlled by the learner. This study addresses that need by developing a Scratch-based self-paced medium on butterfly metamorphosis.

Addressing this research gap, this study uses Scratch to develop an interactive learning medium grounded in the principle of self-paced learning. The application is structured using clear static imagery, concise instructional text, and user-controlled navigation buttons. Under this user-controlled system, instructional materials do not transition automatically; the software pauses until the student has finished reading and manually enters a navigation command.

The objectives of this study are threefold: (1) to design and develop a fully functional Scratch-based interactive science medium on butterfly metamorphosis, (2) to test the functional flow and block-programming logic of the medium, and (3) to describe students' responses to the medium during limited field testing at SDN Nggembe.

2. Literature Review

Interactive Learning Media in Elementary Science

Interactive Learning Media (MPI) is an instructional delivery system that combines media elements such as text, graphics, audio, and basic interactive mechanics to create a two-way communication channel between the student and the learning material. A systematic review of studies on elementary science learning concluded that educational games, as interactive media, attract students' attention and increase engagement and motivation during the learning process (Sari & Rohmani, 2024). Interactive digital products are also commonly evaluated through user perceptions. For instance, a chatbot developed as an interactive alternative to traditional textbooks was evaluated through a survey of 45 respondents, and its author emphasized that the findings reflected perceived accuracy rather than expert-verified accuracy (Arsyad, 2026). This distinction is relevant for the present study, which also relies on students' responses.

Scratch as a Development Platform

Scratch is a visual, block-based programming language developed by the MIT Media Lab, in which event-driven programs are built by snapping code blocks together (Resnick et al., 2009). It is widely regarded as easy for novices to start with while still supporting varied projects, which makes rapid prototyping of customized educational media possible. In elementary settings, Scratch has been used to develop interactive learning media judged feasible by experts, teachers, and students (Kartika & Trimurtini, 2026; Maola & Irianto, 2023), to support students' construction of mathematical concepts (Anabousy et al., 2023), and to make science lessons more engaging and easier to understand for fourth-grade students (Bozan et al., 2025).

Multimedia Learning Principles Applied in the Media

The cognitive theory of multimedia learning assumes that learners process words and pictures through separate channels of limited capacity and must actively select, organize, and integrate the incoming information (Mayer, 2009). Mayer's later synthesis groups evidence-based design principles according to the type of processing they support: principles that reduce extraneous processing (e.g., coherence, signaling, and redundancy), principles that manage essential processing (e.g., segmenting, pre-training, and modality), and principles that foster generative processing (Mayer, 2021). A meta-meta-analysis of 29 systematic reviews found robust support for several of these effects, including coherence, signaling, and segmentation (Noetel et al., 2022). Table 1 relates the principles applied in this study to the corresponding Scratch features. The signaling and modality principles (e.g., highlighting cues and narration) were not implemented in the current version and are noted as directions for future improvement.

Table 1. Multimedia learning principles and their implementation in the Scratch-based media.

Principle	Design intention	Implementation in the Scratch media
Coherence (Mayer, 2021; Noetel et al., 2022)	Exclude extraneous material to reduce extraneous processing.	Clear static illustrations, no hyperactive animation, and instructional text limited to fewer than 40 words per screen.
Segmenting (Mayer, 2021; Rey et al., 2019)	Present the lesson in learner-paced segments instead of a continuous unit.	Content is divided into two sub-topics (general metamorphosis and the four-stage butterfly cycle), each shown on separate screens.
Learner control (self-pacing) (Noetel et al., 2022; Rey et al., 2019)	Allow the learner to adapt the presentation pace to individual needs.	Play, Next, Back, and Menu buttons; the display pauses until the student acts, and there are no automatic slide transitions.
Practice with feedback (van der Kleij et al., 2015)	Provide self-testing with feedback after the learner answers.	Ask-and-wait quiz with automated instant feedback and a 25-point scoring increment.

Cognitive Load Theory and Self-Paced Learning

Cognitive Load Theory emphasizes that working memory has strict processing limits (Sweller, 1988; Sweller et al., 1998), and the theory has continued to develop and to inform the design of educational technology (Sweller, 2020, 2023). When multimedia applications use fast automated transitions, the presentation itself can consume working memory and may increase extraneous cognitive load (Mayer, 2021; Sweller, 2020). Self-paced learning, in which the user controls the pace of the lesson through navigation buttons, allows learners to adjust the speed of presentation to their own needs. A meta-analysis of 88 comparisons found that segmenting multimedia instruction produced small to medium effects on retention and transfer and reduced overall cognitive load, although it also increased learning time (Rey et al., 2019). Table 2 outlines the conceptual differences between three instructional delivery models.

Table 2. Conceptual comparison of instructional delivery methods in elementary science (authors' synthesis based on (Mayer, 2021; Noetel et al., 2022; Rey et al., 2019)).

Delivery Method	Pacing Control Mechanism	Risk of Cognitive Overload	Expected Student Engagement
Conventional Textbook	External (Teacher-driven)	Low to Medium	Low (Passive reading)
Auto-playing Animation	System-driven (Fixed timer)	High (Split-attention)	Medium (Spectator mode)
Self-Paced Scratch Media	Internal (Student-controlled)	Low (Optimized load)	High (Active interaction)

Note. The ratings in Table 2 are qualitative and represent a conceptual synthesis of the literature; they are not empirically measured indicators.

3. Research Methods

This study used a researcher-designed development framework rather than a single standardized model. The framework draws on the generic stages of software development and prototype-based development, which combine requirement definition, design, implementation, and testing with user feedback and have been applied in educational systems (Agustianingsi & Yaqin, 2026; Bjarnason et al., 2023; Naufal & Furqan, 2026). Other Scratch-media studies adopted the ADDIE

model (Kartika & Trimurtini, 2026; Maola & Irianto, 2023); the present framework is simpler and does not include a separate expert validation stage, which is acknowledged as a limitation. The four stages are shown in Figure 1.

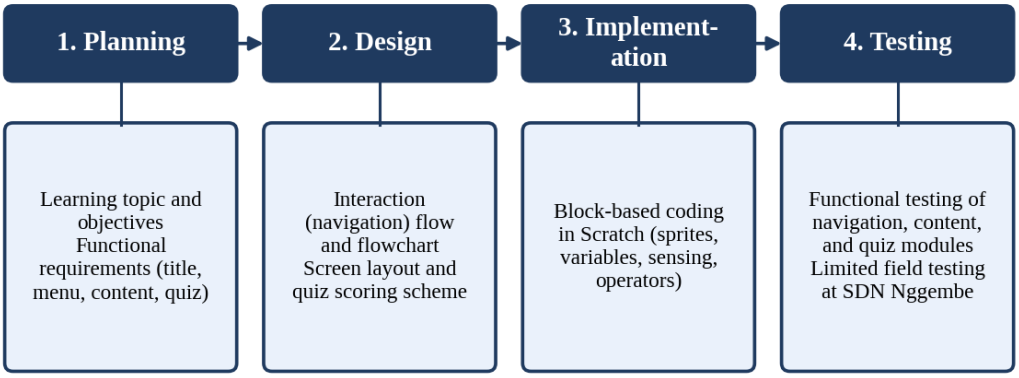

Figure 1. Stages of the researcher-designed development framework.

Planning. The learning topic (butterfly life cycle), the objectives, and the functional requirements (title, menu, content, and quiz modules) were defined. **Design.** The interaction flow, flowchart, screen layout, and quiz scoring scheme were designed. **Implementation.** The design was translated into block-based code in Scratch using sprites, variables, sensing blocks, and operators. **Testing.** The media was tested for functionality (navigation, content, and quiz modules) and then tried out in limited field testing at SDN Nggembe.

The user interaction flow was mapped in the flowchart shown in Figure 2. Because the media offers choices (*Materi* or *Evaluasi*) as well as Next and Back buttons, the flow is not entirely linear but contains branching paths. The main steps of the flow are as follows, and Figure 2 summarizes them:

1. **Initialization:** The user launches the Scratch application.
2. **Start Screen:** The system displays the title banner, school background, and an interactive "Play" button.
3. **Main Menu Interface:** Upon clicking Play, the application shifts to a central hub containing two primary branches: *Materi* (Learning Content) and *Evaluasi* (Quiz).
4. **Content Execution (Self-Paced):** If the user selects *Materi*, the system serves two sub-topics (General Metamorphosis and the 4-Stage Butterfly Cycle). The display stays on concise text blocks until the user presses the Next or Back arrow sprites, and the Menu or Home button returns the user to the main menu.
5. **Interactive Evaluation:** If the user selects *Evaluasi*, the system runs an automated multiple-choice test that uses conditional if-then-else scoring.
6. **Termination:** The system tallies the final score and offers an option to return to the home screen.

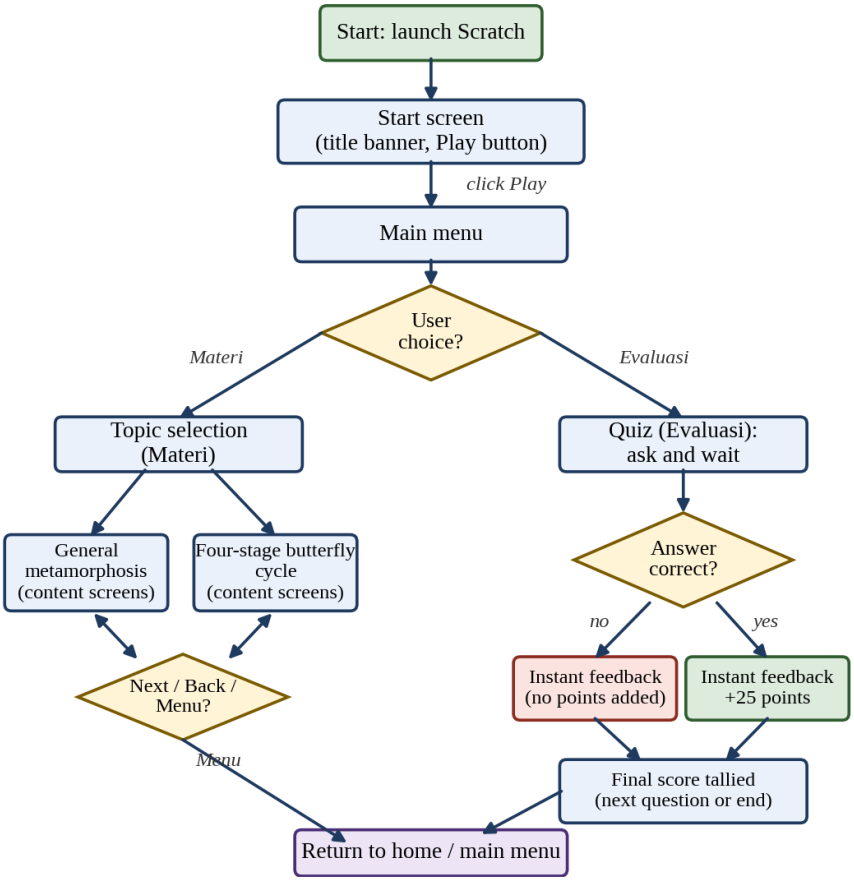

Figure 2. Navigation (interaction) flow of the Scratch-based learning media.

The instructional text was limited to fewer than 40 words per screen to support concise presentation and readability. This design decision follows the coherence and segmenting principles (Mayer, 2021; Noetel et al., 2022) and the cognitive load consideration that young learners have limited working memory capacity (Sweller, 2020). The 40-word limit is a design decision made by the researchers, not an empirically derived threshold.

The quiz module awards 25 points for each correct answer and shows feedback immediately after each response. The 25-point increment was chosen so that four correct answers equal the maximum score of 100 on a conventional 0–100 scale, and the quiz was kept to four items to fit the limited attention span of fourth-grade students and to remain consistent with the concise, self-paced design. Meta-analytic evidence indicates that feedback in computer-based environments benefits learning, with explanatory feedback producing larger effects than feedback on correctness alone (van der Kleij et al., 2015).

Testing had two parts. Functional testing checked the navigation, learning content, and quiz modules for broken links and scoring errors, in line with functional testing practices reported for educational software (Agustianingsi & Yaqin, 2026; Naufal & Furqan, 2026). Limited field testing was then conducted with fourth-grade students at SDN Nggembe, and their responses to the media were recorded descriptively. No pretest–posttest or cognitive load instrument was used, so the findings reflect students' perceptions rather than measured learning outcomes (Arsyad, 2026).

4. Results and Discussions

Results

The development produced a desktop-compatible Interactive Learning Media compiled in the Scratch engine. The results are reported against the functional requirements defined in the planning stage (Table 3). All predefined functional components, including navigation, learning

content, and evaluation modules, were successfully implemented, and functional testing found no broken links across the title, menu, content, and quiz modules.

Table 3. Functional requirements and implementation status.

No.	Functional requirement	Implementation status
1	Start screen with title banner and Play button	Implemented
2	Main menu with *Materi* and *Evaluasi* branches and a persistent Home icon	Implemented
3	Topic selection between conceptual definitions and biological stages	Implemented
4	Self-paced content screens with Next and Back navigation, no automatic transitions, and fewer than 40 words per screen	Implemented
5	Quiz module with ask-and-wait input, conditional scoring, 25-point increments, and instant feedback	Implemented
6	Final score display with an option to return to the home screen	Implemented

The user interface is distributed across five screen environments:

1. **Start Screen:** Displays a bright, child-friendly illustration of an elementary school building flanked by boy and girl student sprites, carrying the title banner *"Mari Belajar Metamorfosis Kupu-Kupu Kelas 4 SD"*.
2. **Main Menu Screen:** Built upon a visual metaphor of a botanical greenhouse, presenting two large, rounded navigation blocks (*Materi* and *Evaluasi*) alongside a persistent, top-left Home icon.
3. **Topic Selection Screen:** Serves as a secondary dashboard allowing the learner to choose between conceptual definitions and biological stage breakdowns.
4. **Instructional Content Screens:** Utilizes an interactive whiteboard layout decorated with floral footers. The text is limited to fewer than 40 words per screen to support concise presentation and readability.
5. **Evaluation Interface:** An automated testing screen driven by dynamic variables.

The mechanics of the evaluation screen rely on Scratch's sensing and variable data blocks. When the quiz triggers `tanya [Pertanyaan...] dan tunggu` (ask and wait), the visual frame pauses. The system captures the user's keyboard input and subjects it to a logical evaluation operator, adds 25 points for a correct answer, and displays feedback immediately.

During limited field testing at SDN Nggembe, the fourth-grade students showed enthusiasm while using the media and reported that the Next and Back controls helped them follow the sequence of butterfly metamorphosis comfortably. These findings are descriptive student perceptions; they do not constitute evidence of improved comprehension or reduced cognitive load.

Discussion

The results show that a Scratch-based medium on butterfly metamorphosis can be built with all predefined modules operating as designed. This is consistent with earlier Scratch-media development studies in elementary schools, which reported products judged feasible by experts, teachers, and students (Kartika & Trimurtini, 2026; Maola & Irianto, 2023). The students' enthusiasm and their reported comfort with self-paced navigation are also in line with reports that elementary students find Scratch engaging and helpful for understanding science material (Bozan et al., 2025).

The self-paced design corresponds to the segmenting and learner-control principles (Mayer, 2021; Rey et al., 2019). Because the benefit of multimedia design was found to be smaller in self-paced than in system-paced environments (Noetel et al., 2022), simple static screens controlled by the learner appear to be a reasonable design choice for young learners. However, cognitive load was not measured in this study, so it cannot be concluded that the design reduced cognitive overload; this remains a hypothesis to be tested.

Several limitations should be noted. First, the evaluation relied on students' perceptions, which, as in other user-perception evaluations of interactive educational products, reflect perceived rather than verified outcomes (Arsyad, 2026). Second, the study did not include a pretest–posttest design or an expert validation stage, and it was conducted in one school with one topic. Third, the quiz feedback can be extended with explanations of why an answer is correct or incorrect, since explanatory feedback has shown larger effects than correctness-only feedback (van der Kleij et al., 2015). Finally, the signaling and modality principles were not applied and could be added in later versions.

5. Conclusion

This study designed and developed a Scratch-based self-paced interactive science learning medium on the butterfly life cycle for fourth-grade students at SDN Nggembe, using a researcher-designed four-stage framework of planning, design, implementation, and testing. All predefined functional components, including navigation, learning content, and the quiz module with instant feedback, were implemented and operated without broken links, and students in limited field testing reported that the self-paced navigation helped them follow the metamorphosis sequence comfortably and showed enthusiasm for the media. The medium offers teachers a free and easily replicated example of applying multimedia design principles in elementary science learning; however, because comprehension gains and cognitive load were not measured, its effectiveness remains to be tested. Future studies should add expert validation and pretest–posttest or cognitive load measurements, extend the media to broader zoological topics, and export the Scratch project file (.sb3) to a mobile-responsive HTML5 or Android (APK) format through wrappers such as TurboWarp so that students can use it independently on their parents' smartphones at home.

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References

Agustianingsi, D., & Yaqin, M. A. (2026). A prototype-based development of a Django web application for optimizing teacher teaching journal management and instructional monitoring. *CODEX: Journal of Software Engineering*, *1*(1), 1–10. https://doi.org/10.33650/codex.v1i01.14452

Anabousy, A., Daher, W., & Bassan-Cincinatus, R. (2023). Scratch as an environment for learning the coordinate system by elementary school students. *Education Sciences*, *13*(7), 724. https://doi.org/10.3390/educsci13070724

Arsyad, G. (2026). Evaluating a large language model chatbot for enhancing historical literacy on Panglima Mayu of the Sumbawa Sultanate. *CODEX: Journal of Software Engineering*, *1*(2), 55–68. https://doi.org/10.33650/codex.v1i2.15485

Bjarnason, E., Lang, F., & Mjöberg, A. (2023). An empirically based model of software prototyping: A mapping study and a multi-case study. *Empirical Software Engineering*, *28*(5), 115. https://doi.org/10.1007/s10664-023-10331-w

Bozan, İ., Demirkaya, H., Çal Pektaş, Ü. T., & Duygu, H. (2025). Investigation of gifted students' views on the use of Scratch activities in science education. *Human Behavior and Emerging Technologies*, *2025*(1), 9822787. https://doi.org/10.1155/hbe2/9822787

Kartika, A. W., & Trimurtini (2026). Scratch-assisted interactive learning media for fraction learning: A development study on fourth-grade students' mathematical representation skills. *Jurnal Kependidikan*, *12*(2), 715–728. https://doi.org/10.33394/jk.v12i2.20618

Maola, P. S., & Irianto, D. M. (2023). Development of interactive media Scratch-based educational games on environmental conservation materials in elementary schools. *Jurnal Kependidikan*, *9*(4), 1290–1300. https://doi.org/10.33394/jk.v9i4.9254

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511811678

Mayer, R. E. (2021). Evidence-based principles for how to design effective instructional videos. *Journal of Applied Research in Memory and Cognition*, *10*(2), 229–240. https://doi.org/10.1016/j.jarmac.2021.03.007

Naufal, M., & Furqan, M. (2026). A mobile-based alumni relationship management system using Extreme Programming: Enhancing digital engagement in Islamic boarding school education. *CODEX: Journal of Software Engineering*, *1*(1), 39–47. https://doi.org/10.33650/codex.v1i01.14456

Noetel, M., Griffith, S., Delaney, O., Harris, N. R., Sanders, T., Parker, P., del Pozo Cruz, B., & Lonsdale, C. (2022). Multimedia design for learning: An overview of reviews with meta-meta-analysis. *Review of Educational Research*, *92*(3), 413–454. https://doi.org/10.3102/00346543211052329

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM*, *52*(11), 60–67. https://doi.org/10.1145/1592761.1592779

Rey, G. D., Beege, M., Nebel, S., Wirzberger, M., Schmitt, T. H., & Schneider, S. (2019). A meta-analysis of the segmenting effect. *Educational Psychology Review*, *31*(2), 389–419. https://doi.org/10.1007/s10648-018-9456-4

Sáez-López, J.-M., González-Calero, J. A., Cózar-Gutierrez, R., & del Olmo-Muñoz, J. (2023). Scratch and Unity design in elementary education: A study in initial teacher training. *Journal of Computer Assisted Learning*, *39*(5), 1528–1538. https://doi.org/10.1111/jcal.12815

Sari, I. P., & Rohmani (2024). Enhancing science learning: The role of educational games in elementary classrooms. *Indonesian Journal of Educational Research and Review*, *7*(3), 581–592. https://doi.org/10.23887/ijerr.v7i3.84074

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

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

Sweller, J. (2023). The development of cognitive load theory: Replication crises and incorporation of other theories can lead to theory expansion. *Educational Psychology Review*, *35*, 95. https://doi.org/10.1007/s10648-023-09817-2

Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251–296. https://doi.org/10.1023/A:1022193728205

van der Kleij, F. M., Feskens, R. C. W., & Eggen, T. J. H. M. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. *Review of Educational Research*, *85*(4), 475–511. https://doi.org/10.3102/0034654314564881