

Adaptive Science Worksheets: Integrating Cognitive Load Theory and Backward Fading for Temperature and Heat Concepts

Ismail Fikri Natadiwijaya^{1*}, Putri Anjarsari¹, Yuli Arti¹, Rahmadevi Maslahatunnisa¹

¹ Science Education Programs, Faculty of Mathematics and Natural Science, Yogyakarta State University, Yogyakarta, Indonesia

¹Email: fikrinatadiwijaya@uny.ac.id

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Abstract. Science learning in junior high school often faces challenges of diverse learning readiness and high cognitive load during learning activities, leading to low conceptual understanding of abstract topics such as temperature and heat. This research aims to develop an adaptive student worksheet based on Cognitive Load Theory (CLT) using the backward fading technique and evaluate its validity. The development followed the Borg & Gall Research and Development (R&D) model, comprising needs definition, prototype design, development, and expert validation. The design systematically scaffolds problem-solving across four distinct stages—from full worked examples, step-by-step fading, to fully independent practice—to optimize working memory capacity. Expert evaluations using Aiken's V formula demonstrated high content validity across all fifteen indicators, with coefficient values ranging from 0.863 to 0.875. Furthermore, overall validation scores reached 95.00% from media experts and 97.75% from subject matter experts. These findings confirm that integrating the backward fading technique into adaptive student worksheets effectively decomposes complex mathematical procedures, minimizes extraneous cognitive load, and is highly feasible for physics instruction in junior high schools.

Keywords: Adaptive learning, student worksheet, Cognitive load theory, temperature and heat, Backward Fading

INTRODUCTION

Science learning naturally requires students to understand abstract phenomena while solving complex problems [1]. The application of adaptive learning is crucial because each student has a different Zone of Proximal Development (ZPD) and cognitive capacity in absorbing the science material [2]. Through an adaptive approach, the system can adjust the level of cognitive challenge in real-time—preventing students who have difficulty experiencing cognitive overload due to overly complex problems, while preventing students from being good at under-stimulation due to tasks that are too easy [3], [4]. By keeping the learning process always within the range of each individual's ZPD, science learning not only becomes more inclusive, but also is able to optimize students' mental engagement and scientific reasoning power continuously [5].

Science learning in junior high school requires an in-depth understanding of concepts regarding temperature and heat materials in accordance with national curriculum targets [6]. Cognitive Load Theory provides an effective framework to optimize students' work capacity during the learning process [3]. The adaptive Student Worksheet facilitates the diversity of students' learning readiness through personal adjustment of material difficulty levels [7]. The implementation of this integration is expected to increase the retention of understanding of science concepts at the secondary education level in a sustainable manner [8].

Most high school students experience misconceptions and difficulty understanding abstract concepts of temperature and heat in the classroom [9]. Conventional student worksheets have not accommodated the difference in student learning speed due to the uniform design of teaching materials [10]. High extrinsic cognitive load often triggers information processing failures due to overly dense display of instructions [11]. Previous researchers have rarely integrated the principles of Cognitive Load Theory into adaptive student worksheet for specific junior high school physics materials [12].

The development of responsive learning media is a very urgent need to prevent a decline in students' interest and science learning outcomes [13]. The researcher designed a learner student worksheet based on Cognitive Load Theory through an adaptive learning approach that adjusts the individual's ability level [14]. One highly effective CLT-based strategy to manage cognitive load is the backward fading technique [15], [16]. Backward fading provides a gradual transition from fully solved worked examples (worked examples) to independent problem solving by removing completion steps backward layer-by-layer. Technically, this

scaffolding strategy optimizes working memory by: reducing Extraneous Load: Eliminating guesswork and structural confusion during initial problem-solving steps. Managing Intrinsic Load: Decomposing complex mathematical procedures into single new processing elements per step. Maximizing Germane Load: Freeing up working memory resources, allowing students to focus on schema construction and deep understanding of temperature and heat concepts.

Despite its potential, previous research has rarely integrated Cognitive Load Theory principles through backward fading into adaptive student worksheets tailored for specific junior high school physics topics. Therefore, this study aims to develop and validate an adaptive student worksheet based on Cognitive Load Theory using the backward fading technique on temperature and heat materials. The product is designed to accommodate diverse learning readiness levels, minimize cognitive overload, and enhance the conceptual understanding of junior high school students in a sustainable manner.

METHODS

The research method used in this study is Research and Development (R&D) by adopting the Borg and Gall development model. According to Borg and Gall [17], this method is a systematic process used to develop and validate educational products to meet certain quality and effectiveness standards. The reason for choosing this model is its comprehensive structure and empirical data based through a series of field trials and periodic revisions. Procedurally, this model includes ten main stages, starting from initial information collection, planning, product draft development, to final testing and dissemination. Through this approach, the resulting products are not only assessed based on theoretical feasibility by experts, but also tested practically to solve real problems in the learning environment. The location of the research is at SMPN 5 Yogyakarta and will be carried out in July 2026 by distributing questionnaires to students and teachers and conducting interviews with subject teachers. This research validates the sustainability of the products developed. This test involves two experts in Science Education, namely an expert lecturer in Science Education at Yogyakarta State University.

This study collects two types of data, namely qualitative and quantitative. Qualitative data is in the form of initial observations as well as criticism and suggestions for improvement from media experts and material experts. Meanwhile, quantitative data is obtained from a Likert scale questionnaire filled out by validators to measure the feasibility of products as supporting teaching materials. All data is collected using validation sheet instruments to evaluate and improve the developed products.

The validity test of the content of the instrument in this study was analyzed using the Aiken's V formula, where the validity coefficient is calculated based on the results of expert judgment on each item. Furthermore, the level of validity of each item is categorized based on the Aiken criterion scale, where the index is categorized as $V < 0.40$ having low validity, is categorized as $0.40 \leq V \leq 0.80$ moderate, and is categorized $V > 0.80$ as high. Items are declared valid and suitable for use if the index value obtained meets the criteria at least in the medium category ($V \geq 0.40$).

RESULTS AND DISCUSSION

Define Result

The results of development research conducted by the researchers produced a product in the form of an adaptive student worksheet based on Cognitive Load Theory through the Backward Fading technique. The researchers collected data from SMPN 5 Yogyakarta City as a school with superior group students based on regional assessment scores. Analysis of needs and difficulties in developing teaching materials was carried out with students and teachers by interviewing subject teachers. Meanwhile, the product trial was carried out by two expert lecturers in the field of media and content. Student worksheets based on the theory of cognitive load in print and electronic form adjust to the needs of teachers and students.

Before conducting the research, the researcher distributed questionnaires to students and teachers and conducted interviews with subject teachers to understand the importance of providing adaptive teaching materials for excellent students. The results of the interviews showed that during science lessons, students needed a learning process that was more adaptive to their cognitive capacity, a learning process that prevented students from experiencing cognitive overload due to overly complex problems, while preventing students from becoming proficient in lack of stimulation due to tasks that were too easy.

Meanwhile, the results of a questionnaire that analyzed the difficulty of the material found that students felt that they were not optimal in understanding the concepts of temperature and heat in science material. On the other hand, temperature and heat material in physics learning has quite complex characteristics because it integrates theoretical concepts with intensive mathematical reasoning. Students are required not only to memorize various mathematical formulations (such as caloric formulas and their changes), but also to master

the problem-solving procedures gradually, starting from variable identification, unit conversion, to algebraic substitution [18]. According to Laili et al. [19], students' difficulties in temperature and heat materials stem not only from understanding concepts, but also from the inability to operate mathematical equations and model problem-solving steps. This is strengthened by the findings of Azizah et al. [20] who noted that the difficulty level of students in the aspect of mathematical calculation of physics reached 90.1%. The results of the questionnaire also showed that students needed teaching materials in the form of student worksheets.

Design Result

The results of the design of the Student Worksheet based on the backward fading technique were prepared in stages to slowly reduce the cognitive load of students along with their increasing independence in solving problems of the Kalor material. Here is a detailed description of the product design results.

Stage 1: Full Worked Example

Students are presented with the problem along with all the stages of solving it, starting from identifying known variables, determining formulas, to calculating the final result. This stage functions as an initial mental model so that students understand the flow of problem solving in its entirety.

Stage 2: First Layer Step Fading (Final Step Removal)

In the next question with a similar context, the entire initial completion structure is still given, but the final calculation step is blanked. Students are only asked to complete the final part of the process of substituting grades into formulas.

Stage 3: Second Layer Step Fading (Removal of Intermediate & Final Steps)

Scaffolding is further reduced by removing the variable value (ΔT) part and substituting numbers in the basic formula. Students are beginning to be required to actively process information and complete more dominant mathematical sequences.

Stage 4: Full Independent Practice

The assistance (scaffolding) was completely removed. Students were given new practice questions and asked to compile all stages of problem solving independently, starting from Known, Asked, to Answered. Here is the form of the description of the above design

Pertanyaan

Langkah 2

- Hitung perubahan suhu

$$\Delta T = 45 - 25 = 20^\circ C$$

$$Q = mc\Delta T$$

Langkah 3

- Gunakan rumus besar kalor. Karena yang dicari adalah massa, maka:

$$Q = m \cdot c \cdot \Delta T$$

$$m = \frac{Q}{c \Delta T}$$

$$m = \frac{42.000}{4.200 \times 20}$$

$$m = 0,5 \text{ kg}$$

Sekarang, giliran kalian yang melengkapi!

Pertanyaan

Ternyata ibu Rani ingin membuat minuman untuk lebih banyak orang. Rani memberikan 84.000 J kalor kepada air dengan suhu awal 25°C hingga suhunya menjadi 45°C.

Berapa massa air yang dapat dipanaskan?

Langkah 1

Diketahui

$$Q = 84.000 \text{ J}$$

$$c = 4.200 \text{ J/kg}^\circ C$$

$$\Delta T = \dots - \dots = \dots^\circ C$$

Sekarang, kerjakan contoh soal berikut secara mandiri.

Pertanyaan

Hari berikutnya, Rani ingin menyiapkan air hangat untuk satu termos. Ia memiliki 126.000 J kalor. Air mula-mula bersuhu 25°C dan akan dipanaskan hingga 45°C. Kalor jenis air adalah 4.200 J/kg°C.

Berapa massa air yang dapat dipanaskan Rani?

PENYELESAIAN

Diketahui

.....

Ditanya (Rumus)

.....

Dijawab (Penyelesaian)

.....

Pertanyaan

Langkah 2

$$m = \frac{Q}{c \Delta T}$$

$$m = \frac{\dots}{(\dots)(\dots)}$$

$$m = \dots \text{ kg}$$

Figure 1. top left full worked example, top right: final step removal, bottom left: removal of intermediate & final steps, bottom right: full independent practice

Thus, the graduation assistance designed through the backward fading technique systematically transitions students from the guidance phase (guided learning) to independent learning (autonomous problem

solving), while ensuring that the understanding of the Kalor concept is built continuously without triggering cognitive burden.

Develop Result

Based on the evaluation conducted by two expert validators, the content validity score for each indicator was calculated using Aiken's V formula. The detailed results of the validity assessment are presented in Table 1.

Table 1. Results of Expert Validation Analysis using Aiken's V

Indicators	V Aiken	Criteria
Eligibility of the content of the material	0,875	High
Application of Backward Fading Technique	0,875	High
Presentation and language	0,875	High
Graphics and internet media	0,875	High
Independence and assessment	0,875	High
Curriculum eligibility and clarity of purpose	0,875	High
Key components and approaches to Deep learning	0,875	High
Application of Backward Fading Technique	0,875	High
Digital assessment and utilization	0,875	High
Linguistics and practicality of the module	0,875	High
Material feasibility and truth of the concept of science	0,875	High
Construction and characteristics of HoTs questions	0,863	High
Deep Learning principles integration	0,875	High
Language and readability	0,863	High
Answer key and scoring guidelines	0,875	High

As presented in Table 1, the analysis reveals that all evaluation indicators achieved Aiken's V coefficient values ranging from 0.863 to 0.875. These scores fall within the high validity category ($V > 0.80$), indicating that the developed instrument possesses high content validity and is suitable for research application.

Discussion

Adaptive learning on this device uses the backward fading technique, which is a method of presenting examples of directional questions in which the help is gradually removed from behind [15], [21]. This technique is a learning strategy based on Cognitive Load Theory that facilitates a smooth transition from worked examples to independent problem solving [16].

The conceptual model of backwards fading can be seen in the following image

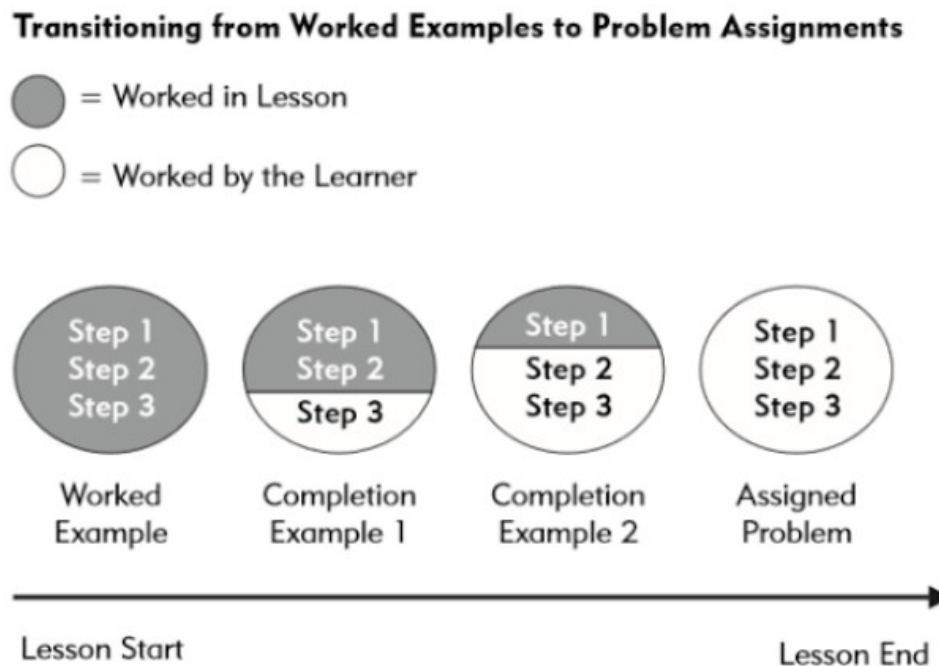


Figure 2. a conceptual models of Backwards faded Completion examples

Specifically, this technique overcomes and manages three types of cognitive load in children's working memory, namely intrinsic load, extraneous load, and germane load [22], [23]. Intrinsic load is a natural load that comes from the level of material difficulty or the complexity of the relationship between concepts [24]. Through this technique, the difficulty of the material is not reduced, but is gradually decomposed [15].

Children only process one new element at each stage (structured scaffolding), thus preventing children from feeling overwhelmed when dealing with complex structured problems [25].

Extraneous load is an unnecessary extra load, which is a "garbage" load or mental disorder that does not support the learning process [16]. Through this technique, the burden arising from trial-and-error when students are given complex problems can be eliminated (extraneous load), so that working memory can be focused on processing material structure (intrinsic load) and forming a germane load scheme [26], [27].

Germane load is a "positive" load, i.e. mental effort used to construct a thought schema and store information into long-term memory [22]. As a result, when extraneous load is trimmed through the presentation of faded examples, space in working memory becomes free for deep information processing [28]. This free space is automatically allocated for schema acquisition. Recent research confirms that backward fading in complex materials affects the breadth of working memory capacity [29]. Children can see the pattern of the relationship between the steps in its entirety from back to front, so that the understanding of the concept becomes much deeper (*deep learning*). The comparison of the effects on children's working memory can be seen in the following table.

Table 2. Comparison of Effects on Students' Working Memory

Learning Conditions	Extraneous Load (Disturbance)	Cognitive Overload Risk	Formation of Understanding Scheme
Directly Given Independent Questions	High (Guessed a lot)	Very High	Low / Slow
Backward Fading	Very Low	Very Low	Maximum:

Thus, the application of the backward fading technique in this adaptive learning device is expected to minimize extraneous load and predict the risk of *cognitive overload*, thereby optimizing children's working memory capacity to form deep learning schemes independently.

CONCLUSION

This study successfully developed and validated an adaptive student worksheet based on Cognitive Load Theory (CLT) utilizing the backward fading technique for junior high school temperature and heat topics. By structuring problem-solving into four progressive stages—transitioning from full worked examples to first-layer step fading, second-layer step fading, and finally independent practice—the worksheet provides systematic scaffolding that effectively mitigates cognitive overload. Content validity analysis using Aiken's V yielded high validity coefficients across all evaluation indicators, ranging from 0.863 to 0.875. Additionally, the overall feasibility scores from media experts (95.00%) and subject matter experts (97.75%) confirm that the product meets high educational standards. In conclusion, the developed adaptive worksheet is highly valid and feasible for implementation in science learning. The integration of backward fading systematically manages working memory load by reducing extraneous cognitive load, decomposing intrinsic material complexity, and maximizing germane load for deep schema acquisition. Future research is recommended to conduct empirical field implementation trials to measure the direct effectiveness of this adaptive worksheet on students' long-term concept retention, mathematical reasoning, and critical thinking skills in diverse classroom settings.

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