Enhancing Critical Thinking Through Reading in a Controlled Environment: A Study Using the BookRoll Tool

Panadda Jaiboonlue, Bansomdejchaopraya Rajabhat University, Thailand
Wasan Na Chai, National Electronics and Computer Technology Center, Thailand
Nattapol Kritsutikul, National Electronics and Computer Technology Center, Thailand

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Abstract
Critical thinking is a vital skill in many aspects of a person's activities, particularly in education, where it enables students to analyze, reason, plan, and self-evaluate. This paper propose a controlled environment designed to train critical thinking through reading, helping students understand logical connections between sentences. This controlled environment is designed for learner's activities to assign several kinds of annotations including logical statement type, keyword and logical linking between sentences to the proper writing text by self-analysis under the supervision of coaches. By engaging in these activities, students can learn to recognize logical expressions and persuasive strategies in writing, gain insight into the author's cognitive processes, and apply these insights to improve their writing abilities. We enhanced the features of BookRoll, an e-book system developed by Kyoto University, to increase its efficiency and better support the tracking of students' reading behaviors. The system records various activities, including time spent on each page, highlighting keywords within sentences, and identifying logical connections between sentences, among other metrics. From experiments, the results showed that the environment helps to increase learning performance. The average precision and recall scores from tagging of the participants using this feature were higher than the participants not using the tool for 0.15 and 0.22, respectively. Moreover, the participants showed significant growth in thinking skills in terms of more correct analysis and critical thinking after using the tool. These results indicated that the thought analysis tool improved users' abilities to become more strategic planners and create more persuasive writing.

Keywords: Critical Thinking, Enhancing Learning, Reading Analysis

Introduction

Learning is a critical process for acquiring both knowledge and skills. One approach to learning, independent learning, involves learners taking initiative in acquiring knowledge or skills through their own efforts, fostering inquiry and critical evaluation. This method is particularly well-suited for self-development during free time, offering learners the opportunity to enhance their thinking and analytical processes through active engagement. Independent learning also provides the flexibility for learners to explore areas of personal interest in knowledge and skill development. However, unstructured or excessive freedom in this process can lead to challenges, such as misunderstanding, the acquisition of incorrect information, or reliance on outdated theories. To mitigate these risks, interventions such as guidance and the setting of boundaries are essential to ensure that learners remain on a productive path of improvement.

The acquisition of knowledge and skills involves distinct learning methods. When learning new knowledge, common approaches include reading and listening, which aid in memorization and understanding. However, acquiring skills requires continuous practice and guidance from experienced individuals. Among various skills, thinking stands out as the most complex and ambiguous to acquire, given the unique cognitive differences among individuals. Thinking skills, though abstract in nature, manifest in practical applications such as decision-making, argument formation, and the use of logic in both speaking and writing. Writing, especially academic writing, provides the clearest expression of thinking skills, as it demonstrates logical reasoning through a structured and intricate thinking process.

One widely applied technique for skill acquisition is learning by example (LBE), which has shown notable success across various applications (Atkinson et al., 2000). In LBE, examples serve as models that possess desirable characteristics, allowing learners to analyze, imitate, or even improve upon them. By extracting these characteristics from exemplary models, learners can develop their own skills. In the context of academic logic and systematic thought, learning thinking skills should involve the study of high-quality, published academic articles, which provide clear examples of logical relationships and thought processes.

This study emphasizes the development of critical thinking skills by analyzing logical relationships within academic writing, focusing on content analysis rather than technical language. To support learners in building these skills, we propose a controlled reading environment using structured activities designed to help students examine both content and logical relationships in academic articles. The BookRoll tool serves as the primary platform for this approach, aiming to enhance learners' cognitive processes by guiding them through the analysis of sample articles and fostering critical thinking. Although learners engage in self-directed learning, expert guidance is provided to define the scope, monitor progress, and offer feedback throughout the process.

The remainder of this paper is structured as follows: Section 2 describes the design of the tool and presents the framework for creating a reading environment that supports the development of critical thinking. This section also discusses the inclusion of behavioral monitoring features through the log system. Section 3 covers the experimental setup, results, and analysis of the outcomes, providing insights into how the tool impacts learners' progress. Finally, Section 4 concludes the study with a summary of findings and recommendations for future improvements to the tool and learning framework. This research demonstrates how integrating a structured reading environment with real-time monitoring can enhance the

development of critical thinking skills, providing valuable insights for both learners and educators.

Methodology

This section presents the design of learner activities and the development of additional features to control the e-reading environment, aimed at enhancing critical thinking skills through article reading. The feature is developed from the conceptual analysis framework developed by W. Na Chai (2017) and is designed to assist users in analyzing written articles by identifying logical statements, contextual relationships, and key concepts. The control the e-reading environment is designed as illustrated in Figure 1.

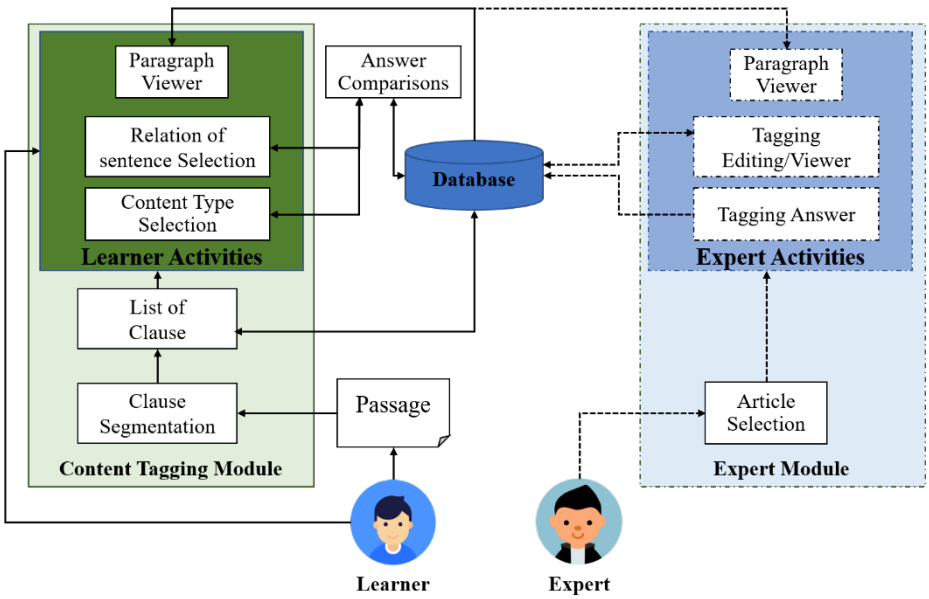

Figure 1: An Overview of the Controlled Environment
Thought Analysis Tool via Reading

The main goal is to help learners analyze the structure of a written article through reading. In addition to practicing analyzing the structure of a written article, learners will be able to discover implicit logical structures within sentences and understand how authors use these strategies to persuade readers. It is expected that learners will develop greater analytical awareness through the analysis process in this controlled environment. Key features of the activities include keyword highlights, content-type tagging, and sentence linking. These activities create an environment that directs the student's analysis of clarifying logical connections in the text, which in turn practices analyzing each section of the reading. The analysis process requires learners to break down the text into individual sentences, highlighting keywords in each sentence to identify the sentence's context. This includes recognizing the main ideas, logical categories of the text, and connections to other sentences, utilizing the add-on features developed in the BookRoll system. By engaging in this process, learners will conduct a detailed analysis of the text and gain valuable insights into the structure of effective writing, allowing them to identify gaps in the author's analytical thinking and apply these insights to improve their writing.

The controlled reading process in this analysis environment is comprised of three key components: BookRoll (an e-book reader), a reading activity module, and a storage system that records activities for analysis and ensures learning accuracy. Instructors can track learner

reading behaviors and review their annotations, providing feedback that guides students without giving away the correct answers, thus helping them avoid misconceptions. This integration of user-driven analysis and expert guidance promotes the development of both metacognitive awareness and critical thinking skills in writing.

BookRoll

BookRoll, an innovative digital e-book reader developed by researchers at Kyoto University, enhances interactive learning and student engagement by supporting active learning, self-regulation, and personalized study experiences. One of its key features is its ability to track and analyze detailed reading behaviors such as page views, time spent on each page, and the use of annotations. This data-driven approach provides educators with actionable insights into student engagement and comprehension, allowing for timely, targeted interventions to improve learning outcomes. Our collaboration with Kyoto University focuses on using BookRoll in the education field and improving its features to better support these learning objectives.

In addition to tracking reading behaviors, BookRoll promotes active learning by enabling students to annotate texts, highlight key concepts, and add personalized notes, fostering deeper comprehension and critical thinking. Integrated with Kyoto University's Learning Management System (LMS), BookRoll allows instructors to monitor student progress in real-time, supporting personalized learning pathways. Its flexibility in accommodating various file formats, including PDFs, enables the use of diverse teaching materials across disciplines. By engaging with digital texts through BookRoll, students also develop metacognitive skills, gaining greater awareness of their own learning processes and improving their academic performance.

Reading Feature

Keyword Highlights.

For each sentence, learners are asked to provide keyword(s) they believe represent the core concept of the sentence. Learners can highlight the term that appeared in the sentence context using a highlighting feature. The number of keywords assigned is limited to 1 to 3 per sentence, and the chosen terms can be either single words or compound words.

This function is designed to encourage learners to analyze and identify the most significant terms that represent the sentence's key concepts, helping them recognize the importance of selecting contextually appropriate terms.

Content Type of Statement Selection.

This function provides a list of logical types for annotating clauses within sentences. Each clause carries a specific idea, often conveying the writer's reasoning, making it a concise summary of the intended content. In the previous version of the tool (Na Chai, 2017), numerous logical types were included, derived from comprehensive writing guidelines, expert analysis, practical writing experience, and feedback from publication reviews. However, users reported that the large number of types and overlapping categories led to confusion and difficulty during selection.

In response to this feedback, the list has been reviewed and refined to focus on the essential concepts of logical statements. The pre-defined content types have been carefully designed to encompass the ideal structures for logical expression in academic writing. This version organizes the types into a two-level hierarchical structure, as in Table 1, ensuring clarity and ease of use for effective annotation.

Table 1: A List of Content Type for Annotation and Their Definition

Content Type		**Definition**
Categories	**Subcategories**	
Declarations	• Declaration of Fact	Statements that convey factual information
	• Declaration of Opinion	Statements that express opinions
	• Giving Details	Statements that provide specific details about core terms of other statements
Emphasis and Contradiction	• Emphasizing	Statements that are restated to emphasize their significance
	• Contradicting Part	Statements that express contradictions to other statements
Examples and Demonstrations	• Giving Example	Statements presenting actual cases or instances related to other statements
	• Giving Demonstration	Statements demonstrating circumstances described in other statements
Causal and Temporal Relationships	• Cause Part	Statements explaining the cause of an event or incident
	• Effect Part	Statements describing the effect or result of a cause
	• Prior Part	Statements describing events that occur before a continuous event/incident
	• Following Part	Statements describing events that follow a continuous event/incident
Conditional and Result Statements	• Condition Part	Statements explaining the condition that triggers an event or incident
	• Result Part	Statements describing the result triggered by fulfilling the condition

Users must assign one of these types to each sentence, with only the subcategories available for annotation. By applying these types, learners are guided to uncover the author's implicit methods and strategies for persuading readers through sentence connections. This process

enables learners to recognize patterns in writing style and explore the underlying logic more deeply, rather than focusing solely on the content's surface.

Sentence Linking.

The relationship between sentences reflects the author's flow of ideas and thought processes within their work. From analyzing well-written published articles, we observe that most sentences are connected to form a coherent and logical network, enhancing the persuasiveness of the text. Readers are thus expected to learn how to express these logical relationships through exposure to effective writing.

Each sentence type, such as cause and effect, often exhibits logical links with others. Learners are tasked with identifying these connections by analyzing the relationships between sentences. They are required to align and assign sentence links using sentence IDs, irrespective of the statement types initially assigned. If a sentence introduces a new concept unrelated to any previous sentences, learners are permitted to assign 'none' to indicate the absence of any prior connections. This exercise fosters deeper engagement with the structure of academic writing and promotes critical thinking by encouraging learners to explore the logical interplay between ideas.

Data Storage

The Log Palette plays a crucial role in the BookRoll system, operating within the Learning and Evidence Analytics Framework (LEAF). It functions as a learning analytics dashboard, collecting and visualizing data based on students' interactions with digital learning materials. BookRoll, an eBook reader, captures key behaviors—such as page views, bookmarks, notes, and time spent on specific sections—enabling both students and educators to reflect on learning patterns. This analytical approach facilitates evidence-based education by helping instructors adapt teaching strategies and gain insights into student engagement and progress (Majumdar et al., 2021; Ogata et al., 2018).

To further promote critical thinking through reading, three key features have been integrated into the system: Keyword Highlights, Content Type Selection, and Sentence Linking. These additions provide deeper insight into students' cognitive processes, allowing instructors to monitor reading behavior more precisely and assess the development of analytical skills.

These features enrich the analytical capacity of the BookRoll system, fostering reflective reading habits and supporting the development of students' analytical thinking through interactive and evidence-based learning as shown in Table 2.

Table 2: Data of Interactions From Learners in Using Tools

Key Design Element	Log Record
General Interactions	• Page viewed
	• Time spent per page
Learner-Highlighted Keywords	• Keyword identified
	• Sentence number
	• Timestamp
Content Type Assignment	• Selected content type
	• Sentence number
	• Timestamp
Sentence Relations	• Related sentence connections
	• Sentence number
	• Timestamp

Evaluation and Discussion

Experiment Setting

To evaluate the effectiveness of the proposed tool, an experiment was conducted comparing learners' thinking processes in independent learning both with and without the tool. The goal was to assess how the tool influences learners' analytical skills by examining differences between unaided learning and tool-supported learning.

The participants consisted of 42 Thai graduate students from a computer science and information technology department. They were randomly divided into 2 groups, with 21 participants per group:

- Group 1: Participants learned without using the tool.
- Group 2: Participants were provided with the tool from the beginning.

Each group was required to select academic articles from a curated pool assembled by a team of experts. The articles were sourced from IEEE Xplore (2015–2022) and selected for their readability and high-quality presentation of logical relationships and expressions. Only articles unanimously agreed upon by all three experts were included in the pool, which ultimately contained 43 papers within the field of computer science and information technology.

Participants were instructed to independently select three articles from the designated pool. They then examined the introduction sections of the chosen articles, using the provided tool to tag each clause according to content type and logical relationships. Throughout this process, an expert offered guidance on interpreting the logical structure of the clauses and provided feedback on tagging decisions. After analyzing each article, participants were required to take a break of at least one hour to mitigate fatigue and minimize cognitive overload.

For the evaluation, the participants' assigned tags—both for content type and clause relationships—were compared against a gold standard created by the expert team. The following metrics were used to assess performance:

- Precision: The proportion of correct tags out of all tags assigned by the participant.

- Recall: The proportion of correct tags relative to the total number of clauses in the article.
- F-Measure: A harmonic mean of precision and recall, calculated as:

$$F1 = 2 * \frac{precision * recall}{precision + recall} \quad (1)$$

This study yielded insights into the extent to which the controlled environment fosters logical reasoning and analytical skills by comparing participants' performance across different learning conditions. Quantitative metrics, including precision, recall, and F-measure, were employed to evaluate participants' accuracy and consistency in identifying and tagging logical structures within academic writing.

Experimental Result and Discussion

The average precision and recall results for the first group (without the controlled environment) and the second group (with the controlled environment), across different tasks content type tagging, relation assignment, and overall performance are presented in Figure 2. These findings illustrate how the controlled environment influences the accuracy and consistency of participants' analytical performance.

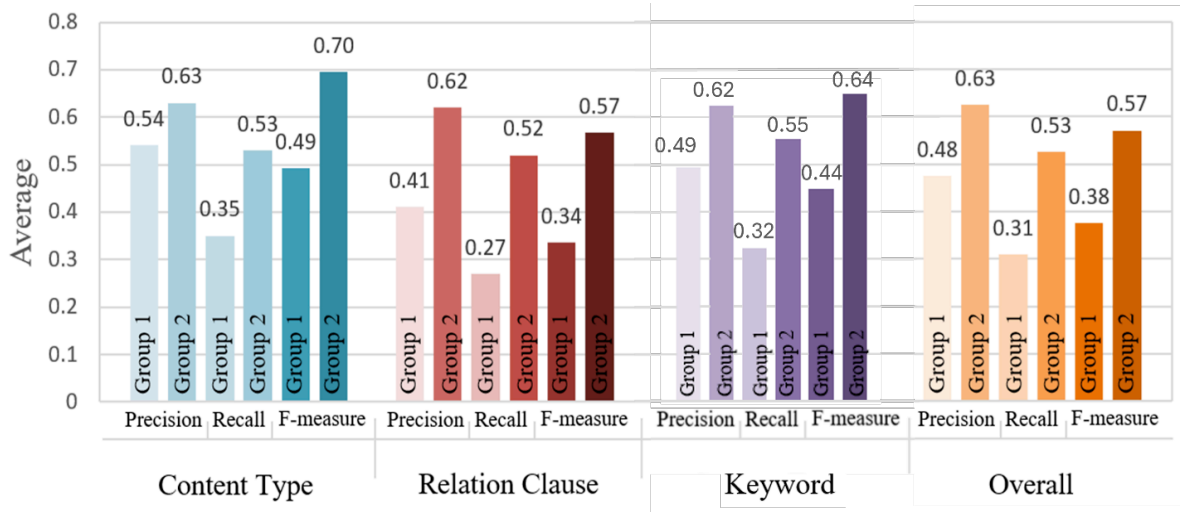

Figure 2: Comparison of Average Results in Precision and Recall Between Participants With Tool and Without Tool

Figure 2 clearly illustrates that the precision, recall, and F-measure scores of the second group (using the controlled environment) surpass those of the first group (not using the controlled environment) in both content type tagging and clause relation identification. Overall, participants who worked within the controlled environment attained higher average precision, recall, and F-measure scores, with improvements of 0.15 and 0.22, respectively. These findings suggest that identifying clause relations poses greater challenges and is more prone to errors than assigning content types, given that understanding clause relations requires a comprehensive interpretation of the entire expression, whereas content type tagging focuses on individual clauses. The controlled environment significantly boosted recall scores by offering an automated clause segmentation feature, which helped increase participants' awareness and reduce the likelihood of omitting clauses. The results also show that the number of correctly identified clauses grew from the second paper onward, even

when participants were no longer using the controlled environment. This pattern implies that the environment helped participants develop a clearer understanding of how to separate clauses and recognize the logical content embedded within them.

In addition, response accuracy improved over time. From post-test interviews, participants indicated that the controlled environment was particularly beneficial for novice learners and those striving to master analytical processes. They emphasized that it serves as a platform to practice critical thinking skills. Through tagging, participants could examine well-written article samples, thereby gaining insights into various writing styles and developing transferable skills for their own academic writing.

Experts interviewed during the experiment noted a marked acceleration in skill development among participants who utilized the controlled environment. They reported a steady reduction in the time required to tag content types and clause relations, alongside a growing sense of confidence among participants as the experiment advanced. Experts further recommended incorporating a visual graph of clause relations derived from the tagged data. Such visualization would explicitly demonstrate the network of logical connections, enabling learners to better grasp and replicate the reasoning process through a more empirical and visually oriented approach.

Conclusion and Future Work

This paper introduces a controlled environment designed to support learning and enhance cognitive processes through the analysis of high-quality examples. The environment provides a structured approach for examining thought processes embedded in academic articles, which often contain complex logical expressions. It guides users in annotating each clause with specific content types (e.g., fact declaration, reason provision, and conditional statements) and identifying relationships between clauses. The objective of this annotation process is to help learners recognize thinking patterns from exemplars and develop their analytical skills.

The experimental findings indicate that the controlled environment significantly improved participants' tagging precision and recall, both in content type selection and clause relation identification. The increase in accuracy between those who used the environment and those who did not was statistically significant. Moreover, the environment bolstered participants' understanding of the importance of analytical and critical thinking skills.

In future work, we plan to visualize the annotated content types and clause relationships as a "network of thoughts," offering an empirical representation of logical connections. We also aim to introduce additional features that utilize the tagged data to suggest logical expressions for academic writing. Another key development will focus on expert involvement, wherein experts will select, tag, or edit articles within the environment, thereby further enhancing its usability and accuracy.

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