ESIC2024 Posted: 13/10/2024

Review of the Content of Elementary School Science Books in Iran Based on Cognitive Load Theory

Javad Keyhan, Sanaz Hossengholizadeh

Department of Education, Urmia Branch, Islamic Azad University, Urmia, Iran
Email: J.Keyhan@iaurmia.ac.ir

Abstract

This study analyzes the content of elementary science textbooks in Iran using Cognitive Load Theory indicators and content analysis methods. The text, questions, and images in the textbooks were examined using a categorization questionnaire and quantitative content analysis based on the Shannon entropy technique. Data collection involved a categorization table and a checklist of John Sweller's cognitive load components. Findings showed that in intrinsic cognitive load, "providing small amounts of information at each stage" (14.89%) was the most emphasized component, followed by "demonstrating relationships between elements" (14.57%), "breaking content into smaller sections" (14.56%), and "providing worked examples" (13.99%). For extraneous cognitive load, "distinguishing each step of problem-solving" (24.66%) received the most attention, while for germane cognitive load, "using more examples" (26.32%) was the most emphasized. Based on these findings, it is recommended that science textbooks for elementary students be organized as short stories to enhance learning and comprehension.

Keywords: Cognitive Load, Science Textbooks, Content Analysis, Shannon Entropy.

1. Introduction

One of the most influential learning perspectives in educational psychology is the cognitive approach (Hennaham & Chen, 2023), which emphasizes that human learning is shaped by internal processes and is not solely influenced by external stimuli (Pengli, 2023). In a centralized educational system like Iran, where a standardized set of textbooks is developed for each grade level across the country, these textbooks serve as the core of instruction in schools (Zolfi et al., 2020). Therefore, aligning textbook content with the cognitive development of students is crucial. Among the key elements of textbook design is educational content, as the way it is organized plays a significant role in determining how learning occurs. The content must align with pre-established goals, particularly cognitive objectives (Valaei et al., 2018). This means that textbooks should match the physical, mental, and emotional capabilities of learners, and it is consistently recommended to select textbooks that align with the curriculum goals (Pourfaz et al., 2019).

Developmental psychologists have significantly influenced education in recent decades, asserting that growth follows specific stages while acknowledging individual differences and slight variations in the timing of these stages (Sharif et al., 2021). Consequently, curricula should be designed to foster student growth and transformation. The primary school years are considered the most critical and sensitive educational period globally, as foundational behaviors and personalities are shaped during this time. This explains why many psychologists, philosophers, and educational theorists focus their attention on this stage(Habibi et al, 2021). Textbook authors also consider psychological theories of learning, including intelligence and memory, in their designs (Thabit-Hossein, 2021). Additionally, mental and physical health are essential factors in any society, and because primary education is so critical, students must be introduced to concepts in their lessons that help them connect past experiences with new ones, a goal often achieved through science education (Saif, 2011).

Therefore, textbook content must be selected and presented in ways that are understandable and appropriate for students. Content analysis is a useful method for identifying hidden biases and tendencies within texts. In analyzing textbooks, especially science textbooks, to assess their suitability for learners' psychological characteristics, content must be evaluated within the framework of psychological theories. As knowledge advances, textbooks, especially in science, need to be continually updated to promote greater cognitive and mental growth in students (Yarmohammadian, 2011). Cognitive Load Theory suggests that the amount of information that can be stored and processed in working memory at any given time is limited, and exceeding this capacity hinders learning (Pastor, 2010). Developed in the late 1970s, Cognitive Load Theory focused on student learning during problem-solving tasks and was further elaborated by John Sweller in 1988 (Seel, 2008). Unnecessary cognitive load, in addition to not contributing to learning, can actually impede it (Tang & Chu, 2020).

The theoretical definitions of cognitive load refer to the constraints of the human cognitive system in learning and instruction. More specifically, cognitive load highlights the limited capacity of working memory to process information (Kalyuga, 2009). It considers the limitations of working memory and can be classified into three types: intrinsic, extraneous, and germane (Reidy, 2015). Intrinsic cognitive load refers to the inherent difficulty of the content, determined by the complexity and interactivity of its elements. Extraneous cognitive load relates to the design and presentation of content, representing poor instructional design. Germane cognitive load is the mental effort learners invest in developing and automating mental schemas, influenced by individual factors such as motivation and interest (Zohar, 2015). Cognitive load theory is based on the accepted notion that working memory has a limited capacity, typically able to hold 5 to 9 pieces of information. If the incoming information exceeds this capacity, it can negatively affect learning. Overloading the cognitive system can result from poorly managed complex content, leading to excessive cognitive load on working memory and impairing the development of mental schemas, thus weakening learner performance (Vasil et al., 2011).

Cognitive load refers to the burden placed on working memory by new information, and excessive load occurs when the cognitive effort required to process the information exceeds the individual’s capacity (Bradford, 2011). Cognitive load is a multifaceted construct, indicating the overload placed on the cognitive system by learning tasks. It accepts the premise that working memory has a limited cognitive capacity, able to hold only a few pieces of information at once.

If the load exceeds this capacity, it severely impairs learning and performance (Hadify & Ito, 2013).

Theorists have long debated how knowledge should be presented to learners and what cognitive processes should be engaged as learners acquire information. Cognitive Load Theory focuses on the load placed on working memory during information processing for learning. It categorizes cognitive load into three types: intrinsic (related to the complexity of content), extraneous (related to presentation), and germane (related to the learner's existing schemas). The modality effect, discussed in this theory, suggests that using both components of working memory—visual and auditory—maximizes memory capacity, making encoding and retrieval easier. Therefore, instructional materials that combine visual and auditory presentations are more effective than those that rely on just one sensory channel. In some cases, combining visual and textual elements can prevent cognitive overload because the learner avoids the mental effort of integrating these elements, thus reducing unnecessary cognitive load(chabook et al, 2023).

Based on this, it is essential to manage intrinsic cognitive load, reduce extraneous cognitive load, and increase germane cognitive load to achieve effective learning outcomes (Zare et al., 2014).

The components of each category were determined as a result of further analysis of the inferences obtained in all three categories of cognitive load: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. The model components are as follows:

Category One: Intrinsic Cognitive Load includes: dividing the content into smaller sections, recalling prerequisite information, showing relationships between elements, providing solved examples, organizing content from easy to difficult, providing auxiliary information, and presenting minimal information at each stage.

Category Two: Extraneous Cognitive Load includes: integrating related information, not presenting familiar information to the learner, presenting the image and text simultaneously and side by side, providing information in a single source, distinguishing each step of problem-solving, not providing clear information, and drawing the learner’s attention to important topics.

Category Three: Germane Cognitive Load includes: using as many examples as possible, presenting solved problems at the beginning of the content, asking learners to solve problems at the end of the content, and providing diverse examples within the content (Hativi & Aito, 2023: 612-613).

Therefore, the researcher intends to examine the science textbooks of the first three grades of elementary school (academic year 2023-2024) based on John Sweller's Cognitive Load Theory and, in conclusion, offer suggestions for improving the content of the science textbooks for the first three grades of elementary school.

2. METHODOLOGY

In this study, content analysis was used, with the unit of analysis being the pages of textbooks, as each page contains text, images, and exercises. The content analysis followed several steps. First, in the pre-analysis phase (preparation and organization), John Sweller's cognitive load components (intrinsic, extraneous, and germane cognitive load) relevant to the first cycle of elementary education were prepared. Content samples were selected for each component to examine the frequency of indicators within the textbooks. In the second phase, the materials (messages) were reviewed to determine the frequency of cognitive load indicators in elementary science textbooks. The third phase involved processing the results, where the data were analyzed, mostly through percentage calculations of indicator frequencies. This research employed a method derived from systems theory to process the data: Shannon's entropy, a new approach to data processing. In information theory, entropy is an index used to measure uncertainty, expressed by a probability distribution. Based on this compensatory model, the content of elementary science textbooks was analyzed. Initially, the indicators were counted according to their frequency in the content (science textbooks for the first elementary cycle). Following this, steps based on the frequency data table were carried out.

The first step involves normalizing the frequency matrix from the frequency table, which is done using a specific formula. In the second step, the information load for each indicator is calculated and recorded in the corresponding columns.

$$E_j = -k \sum_{i=1}^{m} [P_{ij} \ln P_{ij}] (\, \mathrm{j} = 1,2,..\mathrm{n}) \qquad K = \frac{1}{\ln m}$$

E_j = represents the information load,

P_{ij} = is the normalized frequency,

m = is the total number of categories,

k =is a constant derived from the natural logarithm of m.

If the absolute frequency or normalized frequency of an indicator is zero, the logarithmic function will result in infinity, making the calculation of Ej and Wj mathematically impossible. To solve this issue, a very small value (0.00001) is substituted for any zero frequencies. Step three, Using the information load of the indicators, the importance coefficient of each indicator is calculated. Any indicator with a higher information load has a greater Wj importance coefficient.

$$W_j = \frac{E_j}{\sum_{j=1}^{n} E_j}$$

3. FINDINGS

In this section, first, by reviewing the theoretical indicators related to the cognitive load theory and analyzing the text and content of the science textbooks for the first stage of elementary education (including the text, questions, and images of the books), a categorization table and a checklist based on cognitive load theory were prepared for each of the above components. These were then analyzed using Shannon's entropy technique to determine the extent to which these science textbooks address the above categories and to assess the importance of each problem-solving stage within their content. The components of cognitive load theory along with their sub-components are shown in Table 1

TABLE 1 COGNITIVE LOAD THEORY COMPONENTS IN SCIENCE

Components	Themes	Indicators
Intrinsic Cognitive Load	Dividing content into smaller sections	The number of self-assessments in the book (Think Station, Science, and Life) that relate to content division.
	Recalling prerequisite information	The number of classroom activities in the book that serve as advance organizers for learners to acquire new material.
	Showing relationships between elements	The number of short sentences (which have less element interaction).
	Providing solved examples	The number of complete examples presented in the book.
	Arranging content from easy to difficult.	The number of examples in the book that are dissimilar and have greater diversity.
	Providing auxiliary information	The number of suggested activities in the book that are dissimilar and have greater diversity.
	Providing minimal information at each stage.	The number of incomplete and fill-in-the-blank examples in the book.
	Dividing content into smaller sections	The number of self-assessments in the book (Think Station, Science, and Life) that relate to content division.
External cognitive load	Merging related information	Related information should be placed close together and integrated, not far apart.
	Not providing familiar information for the learner	Presenting new material without prior learning.
	Presenting the image and its text simultaneously and side by side.	Presenting the image and its text simultaneously and side by side.
	Providing information in a single source	Educational images and text should be presented together both spatially and temporally.
	Distinguishing each step of the problem-solving process	Each step of a problem must be presented separately from the other steps and should be distinguishable from one another.
	Lack of clear information	Absence of labels and written explanations in an image that is inherently clear.
	Attracting the learner's attention to important content	Using key words and emphasis.
Optimal cognitive load	Using as many examples as possible	Using questions for teacher feedback.
	Presenting solved problems at the beginning of the content	Using images after the teacher's question.
	Requesting problem-solving from learners at the end of the content	The number of self-assessments in the book (at your disposal).
	Providing diverse examples in the content	The number of illustrations in the book.

Question 1: How much attention do the textbooks for the first grade of elementary science give to the intrinsic component of Sweller's cognitive load theory?

In the first step, we form the decision matrix. To create this decision matrix, it is sufficient to obtain the qualitative evaluation of each option relative to each criterion if the criteria are qualitative, or to use the actual numerical evaluation if the criteria are quantitative. In this section, to create the decision-making matrix, the frequency of cognitive load in the first grade of elementary education has been examined, and the data from this table has been normalized based on the Shannon entropy method, which is shown in the next table. After that, based on the data obtained from the second phase, the amount of information load has been determined, and finally, in the third phase using the Shannon entropy technique, the importance coefficients of the components and the obtained information have been determined to identify which component of intrinsic cognitive load received the highest level of importance and attention.

TABLE 2 THE AMOUNT OF INFORMATION LOAD AND THE COEFFICIENT OF IMPORTANCE OF INTRINSIC COGNITIVE LOAD

Themes	First Grade	Second Grade	Third Grade	Information Load	Coefficient of Importance	Rank
Dividing content into smaller sections	0.3151	0.4384	0.2466	0.7723	0.1456	3
Recalling prerequisite information	0.3519	0.2593	0.3889	0.7825	0.1391	6
Showing relationships between elements	0.2383	0.3304	0.4313	0.7721	0.1457	2
Providing solved examples	0.3784	0.2523	0.3694	0.7812	0.1399	5
Organizing content from easy to difficult	0.2750	0.2875	0.4375	0.7755	0.1435	4
Providing supplementary information	0.3967	0.3223	0.281	0.7851	0.1374	7
Providing minimal information at each stage	0.2397	0.2893	0.3058	0.7671	0.1489	1

The results of the above table indicate that, respectively, the component "providing minimal information at each stage" from intrinsic cognitive load has an importance coefficient of 14.89% in the elementary science books for the first grade, receiving more attention than other components. Following this, the showing of relationships between elements has an importance coefficient of 14.57%, dividing content into smaller sections has an importance coefficient of 14.56%, organizing content from easy to difficult has an importance coefficient of 14.35%, and providing solved examples has an importance coefficient of 13.99%, ranking next in importance.

Question 2: How much attention do the elementary science books for the first grade pay to the external component of Sweller's cognitive load?

TABLE 2 THE AMOUNT OF INFORMATION LOAD AND THE COEFFICIENT OF IMPORTANCE OF EXTERNAL COGNITIVE LOAD

Themes	First Grade	Second Grade	Third Grade	Information Load	Coefficient of Importance	Rank
Merging Related Information	0.3582	0.2836	0.3582	0.7884	0.2116	3
Not Providing Familiar Information for the Learner	0.2857	0.3214	0.3929	0.7861	0.2139	2
Presenting the image and text simultaneously and alongside each other	0.3666	0.2904	0.3430	0.7891	0.2109	5
Providing information in a single source	0.3103	0.3793	0.3103	0.7891	0.2108	4
Differentiating each step of problem-solving	0.3548	0.1935	0.4516	0.7534	0.2466	1
Not providing clear information	0	0.2000	0.8000	0.7610	0.1939	6
Attracting the learner's attention to important content.	0	0.6400	0.8400	0.7117	0.1843	7

The results of the above table indicate that the component "distinguishing each stage of problem-solving" from external cognitive load has received the most attention in the elementary science books of the first grade, with an importance coefficient of 24.66%, followed by "not providing familiar information for the learner" with an importance coefficient of 21.39%.

Question 3: How much attention do elementary science books give to the desirable component of John Sweller's cognitive load theory?

TABLE 3 THE AMOUNT OF INFORMATION LOAD AND THE COEFFICIENT OF IMPORTANCE OF OPTIMAL COGNITIVE LOAD

Themes	First Grade	Second Grade	Third Grade	Information Load	Coefficient of Importance	Rank
Requesting learners to solve problems at the end of the content.	0.1905	0.5079	0.3016	0.7368	0.2632	1
Presenting solved problems at the beginning of the content.	0.1860	0.3953	0.4186	0.7533	0.2052	3
Requesting learners to solve problems at the end of the content.	0.3333	0.1905	0.4762	0.7469	0.2105	2
Providing diverse examples in the content.	0.2222	0.4259	0.3519	0.7684	0.1926	4

The results of the above table show that, in order, the component "using as many examples as possible" from the desirable cognitive load has a significance coefficient of 26.32% in the first-grade elementary science textbook, which has received more attention than other components.

4. CONCLUSIONS

The present research was conducted to examine elementary school textbooks based on cognitive load theory; the results indicated that the cognitive load of the content in the textbooks is above average, meaning that the content of these books imposes excessive cognitive load on elementary school students.

In analyzing the content of experimental sciences in the first grade of elementary school, the ranking of internal cognitive load components shows that providing little information at each stage has the greatest importance in internal cognitive load. This is due to the limited teaching materials or minimal discussion about the lessons, which creates this issue, and this cognitive load reduces learning among students. The results obtained are consistent with the findings of Velayati et al. (2018), and also align with the results of Razazadeh (2020). External cognitive load arises from the elements and design of educational content and its presentation to the learner. For example, presenting educational content visually and auditorily typically imposes less cognitive load on the learner’s working memory compared to when the same educational content is presented solely in a visual format. The reason for this is that working memory consists of two channels: visual and auditory, and the capacity of each of these channels is limited. Especially in elementary students who pay more attention to their environment and less to lessons, and are more engaged in childlike mischief, providing educational content that is solely visual can maximally utilize only half of the capacity available in working memory. In this regard, analyzing the content of first-grade experimental science textbooks, considering John Sweller's external cognitive load, is particularly important. From this perspective, the highest importance among the external cognitive load components is related to distinguishing each step of problem-solving. If a lot of cognitive resources are spent on external load, there will be few resources left for desirable cognitive load. Therefore, we should reduce external cognitive load as much as possible. The results obtained align with the findings of Abdi (2020) and are also consistent with Razazadeh’s research (2020). Desirable cognitive load refers to the mental efforts exerted by the learner to learn new educational content and to autonomize their learning and acquire mental schemas; therefore, mere memorization and repetition are no longer sufficient. The learner themselves must engage in deep thinking, inquiry, and question-and-answer. Research findings indicate that an inquiry-based approach in science is essential for this subject and directly affects the way learning occurs. There needs to be a more conducive environment for focusing on this component in elementary science books. In this context, analyzing the content of first-grade experimental science textbooks, considering Sweller's desirable cognitive load, is particularly important. From this perspective, the highest importance among the desirable cognitive load components is related to using as many examples as possible, which indicates that increasing the number of examples in the textbook leads to increased learning. Therefore, to enhance learning, the science textbook should place special importance on numerous examples. The results obtained are consistent with the findings of Abdi (2020) and also align with Razazadeh's research (2020). Based on the findings of this study, several suggestions are made to improve the design of educational content in elementary science books: reduce unnecessary complexities: to reduce internal cognitive load, content should be presented simply and stepwise, avoiding unnecessary complexities. This helps students easily comprehend and learn effectively; use multiple sensory channels: to reduce external cognitive load, it is recommended that educational content be presented in a multimodal way (visual, auditory, and practical). This approach reduces pressure on working memory and enhances understanding and learning; increase examples and inquiry activities: to increase desirable cognitive load, science books should include more examples and inquiry activities. This helps students better understand concepts and strengthens their critical thinking and problem-solving abilities; reduce the number of experiments and increase group activities: instead of focusing on numerous experiments, the number of experiments should be reduced, and opportunities for student creativity and exploration should be provided. Increasing group activities and using open-ended questions can foster creativity and discussion among students. Ultimately, it is suggested that instead of focusing on numerous experiments in each lesson, the number of experiments should be reduced, and opportunities for creativity and exploration by the students themselves should be created. More content that is labeled as group discussion should be increased to facilitate exchange and dialogue, and to foster creativity, it is better to use open-ended questions and increase their number. Considering the results obtained from this study and the analyses conducted, it appears that attention to cognitive load principles in the design of educational content can significantly impact the learning process of elementary students. By reducing internal and external cognitive load and increasing desirable cognitive load, it is possible to improve learning quality and achieve educational goals. Attention to these principles and implementing the proposed changes in textbook design, especially in science lessons, can help enhance students' cognitive and scientific abilities and lay the groundwork for their academic and career success in the future.

WORKS CITED

Chabook, F. A., Keyhan, J., Hassani, M., Sameri, M., & Feyzi, A. (2023). Evaluating The Quality of Higher Education From The Perspective of Students: A case study of Urmia University of Medical Sciences. Research in Teaching, 11(1), 39-22. doi: 10.22034/trj.2023.62701

Habibi Azar, A., Keyhan, J., & Talebi, B. (2021). A Phenomenological study of teachers' lived experiences on the challenges of holding in-service training courses by Ministry of Education. Technology of Education Journal (TEJ), 15(4), 743-756. doi: 10.22061/tej.2021.7507.2546

Hadfi, R., & Ito, T. (2013). Uncertainty of cognitive processes with high- information load. Procedia-Social and Behavioral Sciences, 97: 612-619.
Hanham, N. F & Chin, R. W. (2023). Virtual interviews and their effect on cognitive load for graduate medical education applicants and programs. ATS scholar, 2(3), 309-316.
Jamshidpour, A. (2011). Study and analysis of the content of elementary science textbooks based on students' cognitive development. Master's thesis, Curriculum Planning Group, Payame Noor University, 32-43.
Kalyuga S. 2009 Managing Cognitive Load in Adaptive Multimedia Learning. New York:75-80.
Kalyuga S. Rapid cognitive assessment of learners' knowledge structures. Learning and Instruction 2006; 16 (1): 1-1.
Kalyuga, S. (2009). Knowledge elaboration: A cognitive load perspective. Learning and Instruction, 19(5), 402-410..
Kirschner, P. A., Sweller, J., & Clark, R. E. (2016). Why minimal guidance during in- struction does not work: An analysis of the failure of constructivist, discovery, prob- lem-based, experiential, and inquiry-based teaching. Educational psychologist, 41 (2): 75-86.
Mayer RE. Models for understanding. Review of Educational Research 1989; 59 (2): 43-
Moreno, R. (2010). Cognitive load theory: more food for thought. Instructional Science, 38, 135-141
Paas, F. van Gog, T & Sweller, J. (2010). Cognitive load theory: New conceptualizations, specifications, and integrated research perspectives. Educational Psychology Review, 22(2), 115-121.
Pastore, R. S. (2010). The effects of diagrams and time-compressed instruction on learning and learners' perceptions of cognitive load. Educational technology research and development, 58(5), 485-505.
Pingli, G. R. (2023). A relationship study of student satisfaction with learning online and cognitive load: Initial results. The Internet and Higher Education, 14(4): 217-226.
Pour Ghaz, Sh., Toumaj, H., & Toumaj, A. (2019). The impact of cognitive load-based instruction on self-concept and mental well-being of students. Journal of Advances in Educational Psychology and Educational Sciences, 3(29), 14-28.
Seif, A. (2011). Developmental Psychology (Psychology of Learning and Education). Tehran: Aghah Publications, 36-48.
Sharifmanesh, M., Ghamrani, D., Naderi, D., & Sajadian, D. (2021). Comparing the impact of cognitive load training versus metacognitive training on internal behavioral problems in first-grade high school female students. Journal of Exceptional Children, 21(4), 127-140.
Sweller, J. Van Merri€enboer, J. J & Paas, F. (2019). Cognitive architecture instructional____design:____20 years and later. Educational Psychology Review, 32(2), 261–262.
Van Gog T, Paas F, Van Merriënboer JJ. Process-oriented worked examples: Improving transfer performance through enhanced understanding. Instructional Science 2004; 32 (1):83-
Van Merri¨enboer J, Sweller J. Cognitive load theory and complex learning: Recent developments and future directions. Educational Psychology Review. 2005; 17 (2): 147–177.
Vasile, C., Marhan, A. M., Singer, F. M., & Stoicescu, D. (2011). Academic self-efficacy and cognitive load in students. Procedia-Social and Behavioral Sciences, 12, 478-482.
Velayati, A., Nili Ahmadabadi, M., Zarei Roarki, A., Sharifi, D., & Saadipour, A. (2018). Designing an educational model based on cognitive load theory through qualitative content analysis and internal and external validation. Quarterly Journal of Educational Psychology, 14(27), 1-27.
Yarmohammadian, M. (2011). Principles of Curriculum Planning. Yadavareh Ketab Publications, 14(59), 55-57.
Zare, M., Sarikhani, R., & Mehraban, J. (2014). Investigating the impact of multimedia educational content designed based on cognitive principles on the level of learning and retention in biology lessons. Quarterly Journal of Cognitive Analytical Psychology, 21-28.
Zolfi, V., Hosseini-Nasab, D., & Azmodeh, M. (2019). The effectiveness of teaching cognitive-metacognitive strategies on cognitive load and working memory of primary school students with special learning problems related to reading. Scientific Journal of Education and Evaluation, 3(15), 37-50.