The Power of Reading Support for Learners: A State-of-the-Art Analysis of Computer-Assisted Reading from an Information Systems Perspective

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Abstract

Reading scientific papers is a crucial skill for students. However, many students in higher education struggle to effectively comprehend scientific texts. To address this challenge, researchers have leveraged computer-assisted reading (CAR) systems to enhance students' reading comprehension abilities on a broader scale. Nevertheless, the research and application of CAR in higher education still lack an organized overview and consistent terminology. This is due to the multidisciplinary nature of the field, which encompasses areas such as Educational Didactics, Human-Computer Interaction, and Information Systems (IS). Therefore, we conduct a systematic literature review on CAR from an interdisciplinary Information Systems perspective. Using the socio-technical systems theory as a lens, we organize and summarize past literature and identify gaps that present opportunities for future research. The main contributions of this paper are the synthesis and consolidation of CAR systems in higher education, providing a foundational basis for researchers investigating the domain of CAR.

Keywords: Reading Comprehension, Education Technology, Students, Assistive Reading, Large Language Models

1. Introduction

Literacy is a critical skill and important measure of people's education (Roser & Ortiz-Ospina, 2016). However, research has revealed that university students often lack a fundamental level of text understanding. About a third of students struggle with reading comprehension (Ntereke & Ramoroka, 2017). They struggle to understand texts fully. Dealing with scientific literature represents an intellectual challenge for undergraduate students as they navigate their educational journey. A critical hurdle that emerges in this context is the development of the ability to effectively engage with, comprehend, and critique scholarly literature (Howard et al., 2018). The process of reading and understanding scientific papers is a skill that is seldom taught explicitly, yet it is a crucial facet of the students' academic and professional development (Barr & Tagg, 1995). Thus, they often find themselves lost amidst the scientific jargon and complex methodologies, struggling to decipher the intrinsic value and applicability of the findings (Cromley & Azevedo, 2007). The lack of reading comprehension among students is the problem. This problem is three-fold: there is a lack of understanding of specialized terminologies (Augustine & Greene, 2002), a lack of clarity about navigating the structure of the paper (de-la-Peña & Luque-Rojas, 2021), and insufficient reading practice (Renaissance, 2018). In effect, this impedes whose ability to extract and interpret essential information effectively. Additionally, limited availability of instructors increases the issue, as students may not receive adequate guidance and coaching (Göldi & Rietsche, 2023). Students have indicated their preference for reading instruction to be incorporated into their undergraduate experience (Howard et al., 2018). Moreover, instructors refrain from teaching reading skills, perceiving their role primarily as information providers rather than cultivators of skills and cognitive processes (Barr & Tagg, 1995; Graesser et al., 2009). Explicit reading instruction boosts academic achievement (Burgess, 2009).

To address these challenges, research and practice have designed computer-assisted reading (CAR) systems to simplify the process of reading comprehension. CAR hold great potential in this context with excel at explaining unfamiliar concepts (Kohnke et al., 2023) and aiding navigation through vast information landscapes (L. Zhang et al., 2010). Given the monumental question-answering dialog and text summarization possibilities enabled through Language Models (LMs) (Lee et al., 2022), it is crucial to delve now into the uncharted territory of CAR to enhance undergraduate students' reading comprehension. The rapid advancements in Large Language Models (LLMs) have made it possible to develop dialog-based systems (Nair et al., 2023) that can serve as partners to support in the learning process

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(Winkler et al., 2020). CAR can engage in dialogues, providing support, to enhance their reading comprehension e.g. of code (E. Chen et al., 2023).

To our knowledge, no comprehensive review of CAR in scientific reading exists in the past two decades. Limited clarity and different terminology from the multidisciplinary backgrounds make it difficult to define the field of CAR. A reason for the lack might be the multidisciplinary nature of the field, which leads to the fragmented literature base.

As Blok et al. (2002) mentioned towards the research field, "although the research literature contains a considerable number of effect studies, it still lacks a comprehensive and detached synthesis". Despite the wide-ranging studies conducted on assistive technologies, the intersection between reading education, education technologies and information systems remain underexplored, underscoring a clear gap in the current research landscape. This becomes vivid by the interdisciplinary character of the literature stream. Despite the ambiguous nature of the characteristics and dimensions of this field, distinct viewpoints emerge e. g. the perspective from the field of reading education focuses on reading comprehension, exploring methods to enhance understanding and assimilate the knowledge embedded within texts (M. Ahmadi & Ismail, 2012; de-la-Peña & Luque-Rojas, 2021). Additionally, there is the education technology perspective that investigates the interaction between systems and readers, and how this relationship could be manipulated to enhance reading outcomes (Augustine & Greene, 2002; Cheung & Slavin, 2012; Jamshidifarsani et al., 2019). Lastly, the technological viewpoint focuses on leveraging recent advancements in LLMs to automate and optimize certain reading tasks, such as text summarization (Carpenter et al., 2020; Lee et al., 2022; H. Zhang et al., 2023). Novel technologies to solve these challenges, such as Machine Learning or Natural Language Processing, still fall rather short. Research lacks interdisciplinary studies, that shed light on the design, the embedding, and possibilities but also the effect of novel information systems on students' reading comprehension skills. The intersection of these diverse perspectives creates a multi-dimensional research space, providing a fertile ground for further investigation and innovation. A framework could help to structure this and synthesize the current research around CAR from different perspectives.

An integrative IS viewpoint is of utmost importance to systematically design, analyze and compare the different CAR systems and their effects on students from different points of view to achieve functioning real-world solutions as well as generate better understanding of how to build better CAR applications (Matook & Brown, 2017; Sidorova et al., 2008). This is the basis to form an impactful research stream that helps to use CAR to create tailor-made learning experiences. A consistent knowledge aggregation of the different characteristics and white spots of CAR literature will help researchers and practitioners to systematically design, compare and evaluate new or existing CAR applications. In this regard the primary objective of this paper is to offer a promising viewpoint for investigating and evaluating a certain IS from a technology-mediated learning perspective (Gupta & Bostrom, 2009) and incorporating the different disciplinary perspectives in the design, demonstration and evaluation of the IS (Sidorova et al., 2008). Hence, in this work, we aim to answer the following research questions (RQ):

RQ1: What is the current state of computer-assisted reading (CAR) systems from a socio-technical systems perspective?

RQ2: What are potential white spots for future research to improve students' reading comprehension systematically from an integrative IS perspective?

2. Theoretical background

2.1 Reading Comprehension in Higher Education

The acquisition of essential reading skills is one of the most important skills required for success in post-secondary education (Archibald, 2010). They enable knowledge assimilation, defined as internalized information (Liew, 2007; Pearson & Gallagher, 1983). In higher education, good reading skills are key for academic and professional growth (de-la-Peña & Luque-Rojas, 2021). Individuals must constantly update and understand new knowledge (Kittur 2017) (Kittur 2017). Students' ability to acquire, develop, and comprehend specific knowledge is restricted when they lack sufficient reading comprehension skills (Howard et al., 2018). To improve students' academic performance, it is crucial to educate them with reading comprehension and thereby enhance their reading skills (Cox et al., 2003).

Reading comprehension is the ability of a reader to interpret not just the explicit content of a text but also its underlying meanings resulting in a mental representation (M. R. Ahmadi et al., 2013). This understanding is an intricate process, resulting from the interaction between the text and the reader. Reading proficiency exhibits a developmental nature, characterized by a continuum of growth. The maturation of reading comprehension, including the ability to engage with academic texts, is intricately

intertwined with the interplay of knowledge, experience, and motivation (Howard et al., 2018). Snow identifies four key factors in reading comprehension: text, reader, task, and context (2002).

2.2 Computer-assisted reading

A Computer-Assisted Reading (CAR) system, as initially described by Atkinson (1966), is a computer-based system for teaching reading completely under computer control. This system is organized to offer individualized instruction, allowing each student to progress at their own pace through materials specifically suited to their aptitudes and abilities. The system encompasses a broad spectrum of reading tasks such as letter-string discriminations, acquisition of an initial reading vocabulary, transfer effects on new vocabulary items, and comprehension of sentences (Atkinson, 1966). Given the multifaceted dimensions of these systems, they provide instruction and support at six phases, exhibiting functionalities analogous to the Six Types of Reading Comprehension Processes—Retrieving, Explaining, Summarizing, Evaluating, Creating, and Elaborating—as proposed by Zhu et al. (2020). The interventions along the reading improve students' reading skills (Hall et al., 2000). The user collaborates with the system to better comprehend and understand a text. Collaborative reading fosters better reading comprehension (C.-M. Chen & Chen, 2014).

IT-based education offers advantages like availability, scalability, and personalization (Winkler & Soellner, 2018). These systems also offer prompt personalized feedback (Serrano-Mendizábal et al., 2023).

Distinguishing characteristics set apart novice readers from expert or highly proficient readers (Howard et al., 2018). Students have varying levels of subject-specific prior knowledge and different levels of experience in reading academic texts. The individual abilities to comprehend texts, highlighting the need for a personalized system tailored to them (Howard et al., 2018).

Continuous use of the system is vital for developing reading skills, requiring explicit instruction, feedback, and extended practice (Serrano-Mendizábal et al., 2023).

2.3 Socio-technical theory as guiding framework for the literature review

We're employing Bostrom and Heinen's 1977 socio-technical framework to systematize our findings. This framework encompasses four key elements: "People," representing the reader; "Structure," detailing the reading context; "Task," denoting reading operations; and "Technology," which highlights the tools used. Its broad adaptability makes it suitable for our study, consolidating diverse research fields like reading education, educational technologies, and human-computer interaction.

3. Method

To answer our first research question, we conducted a systematic literature review based on Webster & Watson (2002), vom Brocke et al. (2015) and PRISMA from Moher et al. (2009). According to Cooper (1988), we started the review by defining what evidence should be included in the review. Our aim was to integrate existing literature on computer-assisted reading through a sociotechnical lens, thereby providing a neutral, conceptual framework for the benefit of other researchers.

Drawing from recent CAR literature reviews e.g., (Blok et al., 2002; Cheung & Slavin, 2012; Hall et al., 2000; Jamshidifarsani et al., 2019), we identified different keywords shown in Figure 1.

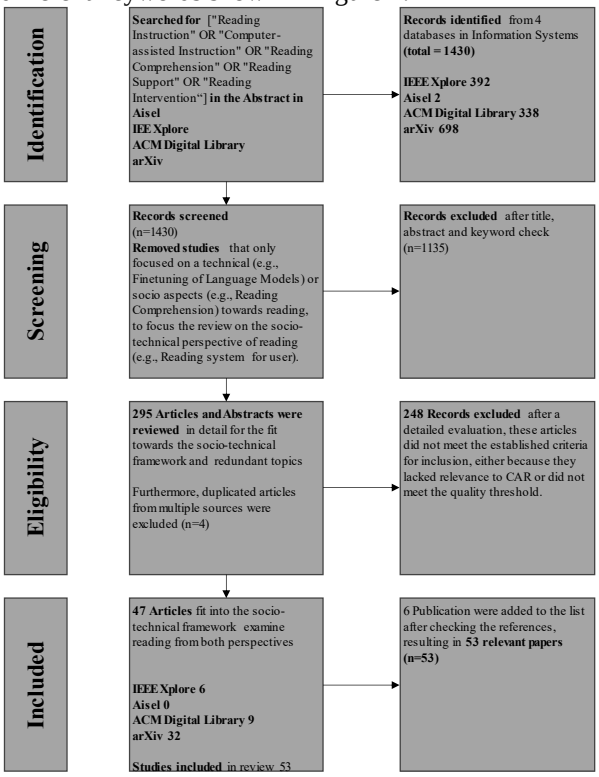

Figure 1. Systematic review using PRISMA (Moher et al., 2009).

We crafted search strings based on Bostrom & Heinen's (1977) sociotechnical perspective and relevant synonyms. We applied the search strings to databases and summarized the found hits in Figure 1.

We examined the titles and abstracts of 1,430 CAR papers published in the past two decades. In relation to our research question, we intend to examine the paper thoroughly using PRISMA by Moher et al., (2009). Figure 1 outlines the four key stages, Identification, Screening, Eligibility, and Inclusion, of our systematic review process. This Figure 1 displays the guideline for the inclusion and exclusion of articles at each phase. We identified 53 relevant papers. We summarize our results in the sociotechnical concept matrix for analysis of computer-assisted reading.

4. Findings

To answer RQ1, we evaluated the literature through a socio-technical lens. Our findings are structured utilizing Bostrom and Heinen's socio-technical framework. This approach is designed to provide an overview of the state-of-the-art of CAR from a socio-technical systems perspective. The intent is to extract the multifaceted dimensions (people, structure, task, and technology) of CAR systems from the papers. In the discussion, we will transfer the identified dimensions within the context of higher education and students' reading.

4.1 People

Through our systematic review, we have found that Computer-Assisted Reading (CAR) systems are not only utilized in education. Contrary to our expectations they are by several distinct user groups. The first dimensions regard the end-user of a CAR. In the literature we found different user groups which designers build systems for. In total, we can distinguish four primary user groups of CAR systems, which we are going to distinguish accordingly:

Professional readers who must engage with lengthy, complex, unstructured texts, which may be too complex for them to easily comprehend (Liang et al., 2023; Wang et al., 2023). These users often work under tight time constraints and require quick understanding of texts. Examples include medical professionals who need to comprehend complex medical texts (X. Zhang et al., 2022) and workers in the construction industry , where diverse individuals must interpret various documents (L. Zhang et al., 2023).

The next group are users who operate in a multilingual environment (Siblini et al., 2021), requiring them to understand texts in multiple languages. This often includes individuals working in translation or those in multinational corporations dealing with multi-language documents.

Furthermore we identified users who are impaired or disabled rely on the inclusive design of CAR systems to compensate for their reading disadvantages (Pannim et al., 2018; Tzouveli et al., 2008). These systems are critical for enabling these individuals to access and comprehend information online.

Lastly we recognize user groups with varying levels of prior knowledge and different characteristics (Cao et al., 2015; Head et al., 2021; Jáquez-Pérez & Villa-Maciel, 2021), who must perform the same tasks e.g. students reading scientific paper with different prior knowledge. A noticeable limitation in CAR systems in the past was the lack of personalization to accommodate the unique needs of individual users (Tzouveli et al., 2008).

4.2 Structure

Our research has identified several contexts and structural environments in which Computer-Assisted Reading (CAR) systems are employed:

Environments that are characterized by large volumes of data that need to be processed. CAR systems are utilized for reading comprehension to manage, interpret, and streamline this data through LLMs at scale (Rae et al., 2022). Knowledge is now being encoded at a scale never seen before, because of this process, systems can now identify concepts iteratively with the reader (Dwivedi et al., 2023).

Secondly, we identified contexts where both the precision of input data and reliability of the CAR system's output are crucial. In these scenarios, users must have a high level of knowledge about the system’s right information output for it to be deemed useful and trustworthy (Choudhury et al., 2022). In contrast, we also found environments where the reliability of the system’s output is of lesser importance e.g. creativity (Stevenson et al., 2022). Systems should not be employed for tasks necessitating complex reasoning. Instead, it could be more effectively utilized as a mechanism for gleaning knowledge from texts written in natural language (Lin et al., 2023). While useful in many Q&A tasks, it is not enough for tasks that require substantial reasoning to solve (Lin et al., 2023).

Another application field are domains where specialized knowledge is necessary, such as legal, medical, technical, or programming sectors (August et al., 2023; E. Chen et al., 2023; Wang et al., 2023).

Additionally, we recognized the use of CAR in situations where guiding a reader's attention is beneficial. CAR systems can highlight key information, aiding readers in navigating through dense or complex texts (Kobayashi & Kawashima, 2019; Yang et al., 2017).

Lastly educational contexts also prominently employ CAR systems. These systems can be instrumental in a variety of settings, from primary schools to universities(Jáquez-Pérez & Villa-Maciel, 2021; Pannim et al., 2018).

4.3 Task

Furthermore, we have discovered through our research that Computer-Assisted Reading (CAR) systems can be deployed for various tasks. With task we mean the specific purpose the system is helping the user to read and comprehend a text. One way CAR can support users is in retrieving: This category comprises activities aimed at extracting specific information from a text. The identified tasks falling within this category include: Defining: The task of identifying and understanding the exact meaning of a term (Head et al., 2021). Highlighting: The process of locating and emphasizing specific portions of a text. Question Answering: A task that requires the extraction of specific information from a text to answer posed questions (Kalpakchi & Boye, 2022).

Users can benefit from CAR through explaining: This category is concerned with activities that involve interpreting or making sense of the information provided in the text. The tasks aligned with this category are explaining with an example: This involves making sense of provided examples and detailing their relevance and application. Scaffolding the user (Chang et al., 2017): This task encompasses providing additional explanations or cues to aid the user's comprehension.

CAR has the capacity to assist and aid users in summarizing (Kirstein et al., 2022): This category relates to activities that require the consolidation and concise representation of the main points of the text. The tasks associated with this category include simplifying (Al-Thanyyan & Azmi, 2021; North et al., 2023). This refers to reducing complex information to its simplest, most essential points.

Support for users is a valuable feature of CAR in identifying and organizing: This category contains tasks that deal with discerning the structure of the text and organizing information accordingly. The tasks relevant to this category are to show relationship between Elements (Li et al., 2020): This involves identifying connections between various elements within the text and linking (Jiang et al., 2022; Pinheiro & Poco, 2022): The task of establishing connections between different parts of the text or between the text and external information sources.

CAR can be a valuable resource for evaluating: This category covers tasks related to assessing the quality, relevance, or credibility of the text's information. The tasks pertaining to this category include recommending further Literature (Saxena et al., 2022) and giving feedback (K.-L. Chen et al., 2020): This task includes providing an evaluation of the information or performance and offering constructive criticism.

Users can rely on CAR for creating: This category involves tasks that require the creation of new thoughts, ideas, or content based on the information read. The tasks falling within this category are Question Generation: This refers to the creation of new questions based on the provided text (Narayanan et al., 2023). Completing Missing Knowledge and adding Information (Guo et al., 2022): This task includes generating new content or information to fill in any gaps in the knowledge and adapting the text to user (Burstein et al., 2007): This task might involve the reformulation or modification of the text based on the user's needs or level of understanding.

4.4 Technology

We have analyzed the technology of Computer-Assisted Reading (CAR) systems and made the following discoveries:

The comprehension ability of the system should not be limited to media text (Su et al., 2023). It can also extend to videos or other artifacts. For example, a CAR system might analyze visual cues and audio components from a video to facilitate understanding.

Furthermore, the technology can be designed with elements to gamify the experience or induce a state of flow in the user (Tsai et al., 2020). This means leveraging elements of game design, such as points, levels, or challenges, to make the reading process more engaging and immersive.

One inherent character of the systems are the interaction via multi-query turns and multiple documents (Feng et al., 2021; Gupta et al., 2020). This suggests a shift towards more conversational and dynamic exchanges between users and systems, where queries can build upon each other rather than existing in isolation. Language models are the backbone for Natural Language Processing (NLP) (Singhal et al., 2022; Todorov & Colavizza, 2022). These need to be configured properly to ensure the highest level of comprehension and responsiveness.

Lastly, the output must be defined and can vary (Dunietz et al., 2020). Text is not always the necessary output. For instance, the system could provide visual summaries, audio feedback, or interactive elements as a response.

5. Discussion

To answer RQ2, we've transferred CAR system findings to higher education contexts and identified research clusters and gaps. These are outlined in Table 1 for other researchers. We also highlight the role of LLMs in transforming reading in higher education.

5.1 Research agenda on computer-assisted reading (CAR) in higher education

Table 1. Preliminary research agenda on computer-assisted reading (CAR) in higher education.

Dimension	Research Opportunities	Research Questions
People	• CAR vs Texts: Evaluate the efficacy of CAR -based interactive materials over traditional long texts in various educational settings • Multilingual CAR: Assess the limitations and opportunities of CAR's multilingual support in enhancing learning outcomes for international students • CAR and Accessibility: Explore the feasibility and impact of CAR modules designed specifically for students with disabilities • Personalized CAR: Investigate how CAR can be fine -tuned for more personalized, adaptive learning experiences for individual students	• How can we enhance reading for students and make learning materials more interactive using CAR? • How can we harness the potential of CAR to foster inclusivity and enhance the reading experience for international students? • How can we utilize CAR to promote increased inclusion and accessibility in reading and higher education for individuals with disabilities? • How can we leverage CAR to provide a customized scientific reading experience that caters to individuals' varying levels of prior knowledge?
Structure	• CAR Trustworthiness: Investigate the reliability and trustworthiness of CAR platforms in higher education, including data security and academic integrity aspects. • CAR use in domain specific study subjects e.g., law	• How can we ensure an appropriate handling of CAR in higher education? • How can we innovate existing study programs and integrate CAR into domain -specific subjects?
Task	• Reading Comprehension with CAR: Examine the role of CAR in enhancing or limiting reading comprehension across different age groups and educational levels • CAR in Workflows: Assess the effectiveness and challenges of integrating CAR into existing student workflows for various academic tasks • CAR System Design: Investigate the optimal design principles for CAR systems, focusing on user experience, accessibility, and adaptability	• How can we integrate CAR into students' workflow when reading academic papers, and which reading tasks are worth integrating CAR for? • How can CAR assist students in enhancing their reading comprehension? • How should the interaction between CAR and students be designed? • How should we design a CAR system? • What are the user requirements for the CAR system? • Which theories could assist in designing the CAR system?
Technology	• New capabilities through Large Language Models • Learning Flow Experience: Investigate how technology can be optimized to create a seamless 'flow' experience in educational settings, enhancing both engagement and outcomes	• How do recent advancements in the field of large language models impact the design possibilities and capabilities of CAR? • How do these advancements open new avenues for use cases related to CAR? • How can we create a smooth reading flow through thoughtful CAR design?

In terms of the people dimension we would highlight the potential of these systems in enhancing the learning experience, particularly for edge case users such as those with reading difficulties (Mastropavlou et al., 2021). For instance, these systems are used to create inclusive academic environments, particularly for disadvantaged or international students within university settings. Their capabilities could be extended to cater to diverse learning needs and levels, promote accessibility, and assist in language acquisition and integration for international students.

In regard to the task and structure at hand, the key finding was that CAR are applied in various reading task (Zhu et al., 2020) e.g. information linking, extraction or summarizing. Researchers have to figure in which tasks exactly reading support can be most beneficially utilized, and how the systems features can be designed for optimal interaction during reading.

5.2 Future Work on CAR in higher education in the realm of LLMs

Past CAR systems faced limitations, e.g. their lack of personalization (Tzouveli et al., 2008). Advances in LLMs like GPT-4 have mitigated these issues, with the ability to handle up to 32,000 tokens in a single prompt (Lin et al., 2023; Terrasi, 2023). Additionally, LLMs excel in reading comprehension tasks (Bommasani et al., 2022) and have enabled the development of dialog-based systems (Nair et al., 2023). These advancements facilitate the creation of more interactive learning material, thereby enriching educational experiences for students (Carpenter et al., 2020). Given these technological strides, it is crucial to investigate CAR systems, particularly focusing on their impact on students' ability to collaboratively read and understand scientific papers.

6. Implications and Limitations

From a practical standpoint, the research underscores the importance of personalizing CAR systems to accommodate the diverse needs and abilities of users. Such personalization, which can cater to factors such as varying language proficiency levels, comprehension capabilities, and reading disabilities, has the potential to significantly enhance user engagement and improve learning outcomes. Furthermore, the study highlights the capacity of CAR systems to manage and interpret large volumes of data. This feature is especially beneficial in professional or academic environments where Students often face the challenge of dealing with large volumes of reading

materials, from textbooks to research papers. Lastly, the findings suggest that reading experiences could be amplified by designing CAR systems with interactive and gamified elements. This has the potential to transform the learning or reading process, making it more engaging and enjoyable and thereby increasing user retention and comprehension.

From a theoretical perspective, the research contributes significantly to the existing knowledge about CAR systems. It illuminates the wide range of user groups and their unique characteristics. Additionally, the findings provide insight into the different contexts and tasks in which CAR systems can be employed. This expands the theoretical understanding of CAR systems' functionalities and their application in various scenarios. Finally, the research underscores the role of ongoing technological innovations in CAR systems. The implementation of language models in natural language processing and the shift towards more interactive dialogue-based user interfaces contribute to the evolving theoretical knowledge surrounding the development and enhancement of CAR systems technology. While our study relies on major databases believed to be representative, the inclusion of additional databases such as Scopus could further enrich future analysis.

7. Conclusion

In conclusion, this paper presents a systematic literature review on computer-assisted reading (CAR) systems in higher education from an interdisciplinary Information Systems (IS) perspective. By employing the socio-technical systems theory as a lens, we have organized and synthesized existing research, aiming to create a comprehensive overview of the field and identify areas for future exploration. Through our investigation, we have highlighted the importance of CAR systems in addressing the challenges students face in comprehending scientific texts. We have created a foundation for researchers investigating CAR in higher education, which hopefully inspires other researchers for future research.

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