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A Cognitive Diagnostic Model of Reading Ability Based on China's Standards of English Language Ability

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ABSTRACT

Traditional English reading assessments in China typically provide a single summative score, without revealing the extent to which students have mastered different aspects of reading comprehension. Cognitive Diagnostic Models (CDMs), as a type of multidimensional latent trait model, offer diagnostic insights by presenting examinees' proficiency levels across a set of predefined skills. Cognitive diagnostic assessments based on these models can deliver multidimensional, fine-grained evaluation results, thus overcoming the limitations of traditional unidimensional score-based assessments. Based on the China's Standards of English Language Ability (CSE), this study constructs a cognitive diagnostic assessment model for English reading. Using college general English reading test papers and the G-DINA model, the English reading abilities of 200 students were diagnosed, and personalized performance reports were generated. A questionnaire survey was conducted to gather students' evaluations and suggestions regarding the feedback reports. The results indicate that the cognitive diagnostic model for English reading, constructed according to the CSE, exhibits good model fit and high diagnostic reliability. The personalized performance reports visually and comprehensively present the strengths and weaknesses of the test takers' reading abilities, providing valuable guidance for students' future remedial learning. This study utilizes a multidimensional assessment approach based on cognitive diagnostic models to evaluate the English reading abilities of Chinese university students, effectively addressing the limitations of traditional assessment methods that typically offer only a single score.

Keywords: China's Standards of English Language Ability; Cognitive Diagnostic Assessment; G-DINA Model; Diag-

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nostic Report

1. Introduction

Reading provides essential language input for learners [1]. It serves as the foundation for students to expand their vocabulary and cultivate other skills such as writing and translation [2]. Considered one of the most critical skills for university students, reading is an indispensable part of college English instruction in China. College English teaching in China refers to the instruction of English language skills at the higher education level. Universities and colleges employ systematic teaching strategies to enhance students' proficiency in listening, speaking, reading, and writing. The goal is to equip students with the ability to effectively use English in academic settings, professional environments, and social interactions. Reading holds a significant position in the fields of foreign language teaching and testing [3]. The "College English Teaching Guide" (2017 edition) emphasizes the need to "fully utilize the multiple functions of evaluation and testing in guiding, motivating, and diagnosing college English teaching." However, both domestic and international English reading tests are predominantly based on Classical Test Theory (CTT) [4] or Item Response Theory (IRT) [5]. These traditional test theories focus on assessing students' macro abilities but overlook the exploration of their internal cognitive processes. Consequently, they fail to provide personalized assessment guidance for students with varying reading levels, thereby hindering student progress [6–9].

Cognitive Diagnosis Assessment (CDA) offers a solution by analyzing the cognitive structures and processes of test-takers to diagnose their mastery of language skills. CDA can provide detailed diagnostic feedback reports and remedial learning suggestions, thus overcoming the limitations of traditional tests that offer only a single overall score [10,11]. CDA promotes the idea of enhancing learning and teaching through assessment and represents the future direction of educational evaluation [12]. In particular, in the field of English reading assessment, CDA plays a significant role in identifying reading attributes, assessing students' reading abilities, and providing reading feedback [13,14]. However, research on CDA primarily focuses on large-scale proficiency tests, where test-takers have significant differences in language proficiency, learning background, and age. This diversity makes it challenging for researchers to implement feedback and carry out remedial teaching based on the diagnostic results [15]. Additionally, some CDA research in China lacks detailed definitions of English reading attributes, and there is no unified standard for defining these attributes, leading to a lack of universality in research findings [16].

This study conducts a diagnostic assessment based on the reading comprehension section of a particular on-campus English examination, using the China's Standards of English Language Ability as the classification standard for reading attributes. The "China's Standards of English Language Ability" (CSE) is a national English proficiency standard developed by the Ministry of Education of China in 2018. It aims to comprehensively measure and describe learners' English abilities, providing a unified evaluation framework for English proficiency across various educational stages, industries, and societal needs. By leveraging the continuity of university based testing and the relatively consistent background of test-takers, this study aims to explore exam information, construct an English reading cognitive diagnosis model, address previous research shortcomings, and improve research methods. Ultimately, it seeks to provide more comprehensive and accurate reading diagnostic feedback for students, teachers, and parents. The following are the research questions:

1. What are the primary cognitive attributes influencing English reading?
2. How can these defined cognitive attributes be utilized to construct a cognitive diagnostic model for English reading?
3. What levels of diagnostic feedback can the constructed cognitive diagnostic model provide?

2. Literature Review

2.1. Reading Model and Ability

English reading is an interactive activity between the reader and the text, involving a multi-layered and complex cognitive processing [17]. Readers need to utilize various cognitive skills, language skills, and non-language skills to integrate and process the information from the text in order to comprehend the entire passage [18].

The "Construction-Integration" (CI) model of reading comprehension is a theoretical framework proposed by American psychologists Walter Kintsch and Teun A. van Dijk in the 1980s [19]. This model explains how readers construct and integrate information from the surface structure and deep structure of a text to achieve understanding. It is divided into two parts: construction and integration.

Construction refers to the process in reading where readers create meaning by combining their prior knowledge with the information presented in the text [20]. These propositions include explicit information (obtained directly from the text) and implicit information (obtained through inference and association). Integration refers to the process where readers combine the generated propositions with their existing knowledge structures to form a coherent understanding model [21]. This process involves organizing, filtering, and integrating information so that new information aligns with prior knowledge.

The CI model divides reading into three levels of mental representation: 1) Surface-level encoding of words and phrases. 2) Text-based representation: This represents the propositional content of sentences and the meaning of the text, including some local coherence inferences. 3) Situation model: This is a micro-world created by the interaction between the text-based representation and the reader's background knowledge, which is crucial for deep comprehension of the text [21–23]. For reading diagnostic assessment, the CI model provides a cognitive perspective for defining the cognitive attributes of reading [24].

Bachman [25] posits that reading ability essentially reflects the use of language ability within the broader framework of the Communicative Language Ability (CLA) model. This model divides language ability into two aspects: language knowledge and strategic competence. Language knowledge includes phonological, lexical, grammatical, semantic, and pragmatic knowledge. Strategic competence involves metacognitive strategies and cognitive strategies [26]. Metacognitive strategies refer to the effective monitoring and control strategies used by readers during reading, such as evaluation strategies, monitoring strategies, and regulation strategies. Cognitive strategies mainly involve the ability to understand the text, memory capabilities, and the ability to retrieve information from long-term memory [27]. Bachman's [25] model of communicative language ability essentially embodies the idea of the reading component model, emphasizing the micro-level skill components of reading. It provides significant guidance for defining the cognitive attributes of reading [28].

2.2. Research on the Diagnostic Model of Reading Ability Based on the China Standards of English Language Ability

In 2014, the Ministry of Education of China invited over 200 experts and scholars from both domestic and international backgrounds to collaboratively complete the China Standards of English Language Ability (CSE). This is China's first comprehensive set of standards covering English teaching, learning, and assessment across all educational stages. It serves as an important reference and basis for future foreign language teaching objectives and evaluation targets in China [29].

The CSE, based on practical language teaching and societal demands, is underpinned by the communicative language ability model proposed by Bachman and Palmer [30]. It defines language ability as the language comprehension and expression abilities demonstrated by language users/learners when using their linguistic and non-linguistic knowledge, as well as various strategies, to participate in language activities on specific topics in given contexts [31]. Reading ability falls under the category of comprehension abilities.

Based on the macro definition of language ability, the CSE divides reading ability into two dimensions: cognitive abilities and comprehension strategies. Each dimension is further divided into several sub-abilities. Specifically, cognitive abilities include recognition and extraction, summa-

rization and analysis, and critical evaluation.

Recognition and extraction refer to the ability of language users to accurately identify and retrieve specific information from the reading material. Summarization and analysis involve the ability of language users to grasp the overall meaning of the reading material, clarify the relationships between informational elements, and make reasonable inferences and predictions based on comparison and summarization. Critical evaluation indicates the ability of language users to reflect on and judge the content, form, style, and intention of the reading material using their existing knowledge. Comprehension strategies are the methods or measures taken to complete cognitive tasks. These are identifiable methods, techniques, and skills used by language learners and are applied throughout the entire reading process [16,32].

The reading ability scale uses three methods—intuitive, qualitative, and quantitative—based on five descriptive characteristics: affirmative, accurate, clear, concise, and independent. It describes the reading ability of Chinese English learners/users across nine levels. Ultimately, it forms a comprehensive reading ability table, six cognitive ability scales, and one comprehension strategy scale.

2.3. CDA

Leighton & Gierl [6] define cognitive diagnosis as a diagnostic method that estimates an individual's latent knowledge state and cognitive skills by obtaining their observable response patterns in a test. Based on cognitive psychology models and using psychometric methods as tools, this approach incorporates cognitive models of task completion into cognitive diagnostic measurement models. This enables the measurement of micro-variables such as learners' knowledge, skills, strategies, and processing processes, providing qualitative and quantitative diagnostic results for students with different cognitive characteristics.

2.3.1. Key Concepts of CDA

1) Cognitive Attributes

In applied linguistics, attributes are understood as the various sub-skills that make up reading ability [33]. These attributes reflect the components of the reading process, which researchers attempt to decompose and test individually. Identifying the main attributes and their relationships involved in the processing goals of the measurement, that is, constructing a cognitive model of abilities, is the starting point and a critical process in cognitive diagnostic research [13]. Cognitive attributes encompass the specific knowledge, skills, and strategies required to tackle a test task effectively. In the realm of reading comprehension, these attributes may include summarizing main ideas, identifying details, making inferences, and more. Defining these attributes can draw from various sources such as test specifications, content domain theory, item content analysis, and audible thinking [7,34].

2) Q-Matrix

Tatsuoka [35,36] is a theoretical pioneer of the Q-matrix, which he argues detects learners' implicit knowledge states and uses observable theoretical models to represent abstract knowledge states. The Q-matrix represents the relationship between specific topics and the cognitive attributes being tested [37]. The relationship between a topic and an attribute can be represented by 0 and 1, where 0 means that the topic is answered correctly, but the attribute is not required, and 1 means that the topic is answered correctly, but the attribute is required [38]. The Q-matrix is a crucial input for applying cognitive diagnostic models to provide diagnostic data on students' skill mastery.

3) CDMs

CDMs are latent variable models used to assess the state of a student's mastery of a range of skills. The CDM combines cognitive psychology, item reflection theory, and statistical modeling. There are more than 120 different Cognitive Diagnostic Models [39], such as the Fusion Model, Attribute Hierarchy Model, and G-DINA Model., which play a great role in the field of education and psychometric [38]. According to its modeling assumptions, CDM has been categorized into non-compensatory, compensatory, and general models [40].

2.3.2. Application of Cognitive Diagnostic Assessment in English Reading Tests in China

Recent research has highlighted the significant role of cognitive diagnostic assessment (CDA) in evaluating second language (L2) reading proficiency. CDA aims to identify students' strengths and weaknesses in specific

cognitive attributes involved in reading tasks, providing a more detailed and personalized analysis of their performance. Below is a review of several studies that utilized different cognitive diagnostic models to analyze English reading proficiency in various student populations. Wu [14] conducted a cognitive diagnostic analysis of a second language reading proficiency test using the Fusion Model. The study identified ten reading cognitive attributes and successfully generated relevant diagnostic information through the Fusion Model fitting process. However, the attribute definitions were relatively broad, which could potentially affect the accuracy of the Q-matrix. Additionally, the study lacked quantitative data analysis to validate the proposed cognitive attributes, leaving some uncertainty about the robustness of the model's application in reading assessment. Ma and Du [16] identified eight reading attributes through a combination of literature review, expert experience, and think-aloud protocols. They employed the R-RUM cognitive diagnostic model to examine these attributes and constructed an English reading cognitive diagnostic model. Based on this model, they developed a diagnostic report framework that provided detailed information for both individual students and groups. While their study contributed valuable insights into English reading diagnosis, it lacked sufficient empirical data to validate the effectiveness of the cognitive diagnostic model. Furthermore, the suitability of the R-RUM model for diagnosing reading proficiency in diverse learner populations remains uncertain and requires further investigation. Zhang [15] focused on assessing the English reading ability of non-English major students at Chinese universities. By analyzing reading scores from university final exams and combining these scores with cognitive diagnostic models, the study generated a personalized reading diagnostic report, offering a reference for evaluating university students' English proficiency. However, the study identified only five reading attributes, which were somewhat broad and might not fully capture the complexity of students' reading abilities. This limitation could affect the comprehensiveness of the evaluation and potentially hinder the development of more targeted instructional interventions. Luo [13] developed an English reading diagnostic test using the G-DINA model to assess students' English reading abilities. The study aimed to provide a more comprehensive reflection of students' reading levels, improving the accuracy of reading assessments. However, Luo's study did not produce personalized diagnostic reports. Instead, it used the test results for stratifying students' proficiency levels, which limited the potential of cognitive diagnostic assessment to provide individualized feedback and actionable insights for improving students' reading skills.

These studies demonstrate the growing interest in using cognitive diagnostic models to assess L2 reading proficiency, as well as the potential of these models to provide detailed and individualized feedback to both students and educators. However, common challenges persist across these studies. One major issue is the broad or vague definitions of reading attributes, which can affect the accuracy and applicability of the cognitive diagnostic models. Additionally, many studies lack sufficient data to validate the effectiveness of the models or the reliability of the diagnostic information provided. Furthermore, while personalized diagnostic reports hold significant potential for improving students' reading abilities, several studies have not fully exploited this feature, limiting the practical impact of cognitive diagnostic assessment. Future research should aim to refine the definitions of reading attributes, collect more empirical data to validate cognitive diagnostic models, and explore ways to optimize the application of personalized feedback in L2 reading assessment.

3. Research Methodology

3.1. Research Site and Subjects

The study was conducted at a comprehensive provincial university in a major Chinese city. With a faculty of 1,200 and an enrollment of over 20,000 students, the university plays a significant role in the local academic community. Its vibrant academic environment, characterized by active student and faculty engagement in English learning, creates favorable conditions for data collection and ensures the smooth progression of the research.

This study followed the principle of having a large sample, with 200 second-year university students selected for the questionnaire phase. These participants had

completed one year of college-level English education and possessed a sufficient level of English proficiency to complete the reading-related tests and questionnaires. To ensure sample representativeness, random sampling was used, giving each student an equal chance of selection. This approach minimized sampling bias and enhanced the reliability and generalizability of the results. Additionally, to ensure data validity and integrity, students with special educational needs and those who did not complete the test or provide complete data were excluded from the study. For the think-aloud verbal protocol, five non-English majors with intermediate to advanced English proficiency were recruited as volunteers (**Table 1**). These participants were selected based on their academic performance, ranking in the top third of their class, and recommendations from their English teachers. Purposive sampling was used to streamline the selection process, focusing on individuals who met the specific criteria aligned with the research objectives. In addition, five-experienced university English teachers, each with over ten years of teaching experience, were invited as experts to identify the cognitive attributes and learning strategies essential for successful English reading. **Table 2** summarized the relevant information on the five experts. These experts were selected through purposive sampling based on their extensive knowledge and expertise in English reading, ensuring the relevance and credibility of their input. All experts were from the same university where the research was conducted, ensuring consistency and alignment with the study's goals.

Table 1. Information of selected students.

Student	Age	Gender	Major	Years of English Learning	Academic Performance
Student 1	21	Female	Economics	8	Top 10% of class
Student 2	21	Male	Business Administration	8	Top 5% of class
Student 3	22	Female	Computer Science	8	Top 15% of class
Student 4	23	Male	International Relations	9	Top 20% of class
Student 5	20	Female	Environmental Science	7	Top 10% of class

Table 2. Information of experts.

Expert	Educational Level	Gender	Age	Research Interest/Field of Expertise	Academic Title
Expert 1	PhD in English Education	Female	45	English reading comprehension, cognitive assessment	Associate Professor
Expert 2	PhD in TESOL	Female	37	English language teaching, reading pedagogy	Lecturer
Expert 3	PhD in English Education	Female	46	Reading comprehension theories, reading and writing skills	Professor
Expert 4	PhD in Applied Linguistics	Male	50	Second language acquisition, reading strategies	Professor
Expert 5	PhD in English Education	Male	35	cognitive assessment, reading strategies	Senior Lecturer

3.2. Research Instruments

This study employed four primary research instruments:

Reading Comprehension Test: The reading comprehension section of the final college English examination from a certain university was selected from the university's test bank. It included three reading passages with a total of 20 questions, all of which were dichotomous single-choice questions. One passage contained 10 information-matching questions, while the other two passages each included five single-choice questions. The test paper was adopted from the College English Test Band 4, a national standardized English proficiency test in China. Particularly, the test battery developed by Du [16] was re-

ferred to, which was considered to be authentic in China's academia. Thus, the test paper used in the study was valid. The test analysis revealed a Cronbach's alpha coefficient of 0.784, indicating good overall reliability.

Statistical Analysis Software R: R is a comprehensive software system for data processing, computation, and plotting, capable of meeting diverse needs through its various plugins (i.e., R packages). For this study, the CDM package, which offers multiple cognitive diagnostic models developed by both domestic and international scholars, was utilized. Specifically, the G-DINA model [41], known for its saturated and compensatory characteristics, was employed for diagnostic evaluation.

Think-aloud protocol: The think-aloud protocol, a method in which cognitive processes are audibly expressed, is used to observe and understand individuals' internal operations during task execution [14]. This protocol encompasses two variations: concurrent think-aloud protocol and retrospective think-aloud protocol, contingent upon the timing of oral reporting [42]. In this study, five selected students participated in a retrospective think-aloud protocol. After completing each meaningful section or sub-question of the reading test, they engaged in dialogue with the researcher, identifying the reading knowledge and strategies used. This verbal articulation of their cognitive processes helps clarify their cognitive state during task completion, thereby validating the reading test items. The entire experimental process was recorded using a tape recorder for subsequent analysis and validation.

Survey: The fourth assessment instrument was a questionnaire designed to evaluate the effectiveness of personalized reading feedback reports. This tool aimed to gather insights into the efficacy of such reports, including the accuracy of cognitive diagnostic assessments and the practicality of learning strategies assessments. The questionnaire consisted of ten items, divided into two distinct areas, as outlined in the appendix: 1) Evaluation of the accuracy of cognitive diagnostic outcomes; 2) Students' perceptions of personalized reading feedback reports. Each item in the questionnaire utilized a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree," allowing for a detailed evaluation of participants' feedback across the specified areas.

3.3. Research Process and Data Analysis

3.3.1. Construction and Validation of Cognitive Attributes for English Reading

Defining the cognitive attributes of reading is critical for this study. Through a combination of literature review, expert consultation, and think-aloud protocols, the attributes were identified. Initially, the researchers based their preliminary list of nine attributes on the reading subscale of the China's Standards of English Language Ability.

Five experts were then invited to analyze and discuss the content of the reading test items. They annotated each test item according to the preliminary list of cognitive attributes and listed any attributes not included or inconsistent with the initial list. Ultimately, seven cognitive attributes were identified: vocabulary, sentence comprehension, extraction of explicit information, connection and synthesis, inference, metacognitive skills, and elimination method.

Following this, five second-year English major students with slightly higher English proficiency than the test participants were invited for the think-aloud protocol. These students, who had a basic understanding of reading skills, were able to introspect and articulate their thought processes more comprehensively. Each student was asked to verbalize their reasoning and thoughts while answering each question, with recordings made with their consent. During the think-aloud sessions, the researcher prompted students to continue if they paused for too long but otherwise did not intervene. The recorded think-aloud data were transcribed, segmented, filtered, and annotated. Attributes recognized by at least four students were retained, while other attributes were re-evaluated based on expert opinions. Attributes with fewer than two mentions were merged or deleted. This process resulted in eight final cognitive attributes, with specific definitions referenced from Li & Suen [43].

3.3.2. Construction of the Cognitive Diagnostic Model for English Reading

The cognitive attributes Q-matrix was constructed based on the 20 test items and the identified cognitive attributes. If a test item required mastery of a specific at-

tribute to be answered correctly, it was marked as 1; otherwise, it was marked as 0. The Q-matrix was revised based on preliminary calculations. The second matrix comprised the test results of 200 participants answering the 20 English reading test items. After identifying the cognitive attributes for English reading, the constructed Q-matrix and participants' response data were imported into the R software. Using the G-DINA model, the researchers diagnosed the mastery of cognitive attributes for each individual, analyzed their reading skills, and discussed the constructs, quality, and issues related to the test items.

3.3.3. Generation of Diagnostic Feedback

Diagnostic feedback should concisely describe the test content, the meaning of scores, and the use of diagnostic information. This study revised and adjusted the diagnostic feedback framework designed by Roberts and Gierl [44] to create a tailored diagnostic feedback form. The goal is for this diagnostic information to effectively support students' future learning development.

4. Data Analysis

4.1. The Construction of a Cognitive Diagnostic Model for Reading

4.1.1. The Definition of English Reading Attributes

For Research Question 1, this study identified eight reading attributes and their definitions, as shown in **Table 3**. Based on the classification of reading abilities from the scale, this study categorizes the reading attributes according to their level of difficulty into recognition, comprehension, inference, and analysis.

Table 3. Reading attributes.

Category	Ability	Description
Cognitive Ability	Recognition	A1: Recognizing General and More Difficult Vocabulary: Understanding general vocabulary/phrases in questions, options, or target sentences. Understanding specialized or more challenging vocabulary/phrases in questions, options, or target sentences.
	Comprehension	A2 Understanding Sentence Meaning: Processing and understanding complex and lengthy sentences, especially those that are critical to comprehension. A3 Understanding the Literal Meaning of Text: Understanding the literal meaning of multiple sentences, including paraphrasing.
	Inference	A4 Inferring Vocabulary from Context: Inferring the meaning of vocabulary/phrases based on context. A5 Inferring Indirect Information from Text: Understanding and inferring the implicit meaning of sentences, paragraphs, or the entire text. A6 Inferring Pragmatic Meaning from Text: Making inferences based on sociolinguistic and sociocultural knowledge.
	Analysis	A7 Distinguishing Relevant and Irrelevant Information: Differentiating between relevant (or important) and irrelevant (or unimportant) information, then focusing on the relevant or important information. A8. Analyzing the Author's Viewpoint/Intention and Summarizing the Passage Theme: Understanding the author's viewpoint, bias, values, or intentions, and summarizing the theme of a paragraph or passage.

Recognition reflects the ability of language users to accurately identify and reproduce specific information from the material read, including the recognition of general vocabulary and more challenging vocabulary. Comprehension and inference refer to the ability of language users to grasp the material as a whole. Through comparison and summarization, they can clarify the relationships among informational elements, enabling them to make reasonable inferences and predictions. This includes five specific attributes, such as understanding the literal meaning of sentences and texts, inferring word meanings from context, and inferring indirect and pragmatic information from the text. Analysis represents a higher level of cognitive ability, characterized by the language user's ability to filter and distinguish textual information, locate and summarize key information, and thus analyze the author's viewpoints and intentions. The attributes defined in this study are more specific and precise, which will facilitate the subsequent annotation of the Q-matrix. Moreover, these attribute definitions are better aligned with the reading comprehension abilities of Chinese university students, making them more effective in accurately reflecting the cognitive processes

involved in reading comprehension.

4.1.2. Constructing the Q-Matrix

Five reading experts were invited to annotate the Q-matrix based on defined attributes, providing a framework for modeling students' attribute mastery probabilities. The experts identified three attributes—identifying difficult vocabulary, inferring indirect information from the text, and understanding the pragmatic meaning of the text—as particularly challenging to judge, requiring further clarification. The resulting Q-matrix is a two-dimensional table with 8 columns and 30 rows, where each column represents a reading attribute, and each row corresponds to a reading test item. Since each of the eight attributes was measured by at least three items, no attribute was excluded from the Q-matrix. Based on the experts' assessments, the researchers developed an initial Q-matrix, which reflects the complex nature of reading comprehension [45,46].

To evaluate the validity of the Q-matrix, an internal consistency analysis was conducted on the experts' annotations. The Fleiss' Kappa coefficient for internal consistency among the five experts was 0.41, indicating moderate agreement [47] and suggesting that the constructed Q-matrix is generally valid. Following this, the study annotated five think-aloud protocols to qualitatively assess the validity of the attributes, leading to a review and subsequent adjustment of the initial Q-matrix. Researchers then analyzed the alignment between the attributes used by students to correctly answer each item and the experts' annotations in the Q-matrix. With the exception of a few items where discrepancies existed between the students' and experts' identified attributes, most items showed strong alignment, thereby providing qualitative validation of the defined attributes. As a result, the final Q-matrix was established in **Table 4**.

Table 4. Q-matrix.

Attributes Items	A1	A2	A3	A4	A5	A6	A7	A8
1	1	1	0	0	0	0	0	1
2	1	0	1	0	0	1	0	0
3	0	1	0	1	0	0	0	0
4	1	0	0	0	1	0	1	0
5	0	0	1	1	0	0	1	0
6	0	1	0	0	1	0	0	1
7	0	0	1	0	0	1	1	0
8	0	0	0	1	0	0	0	1
9	1	0	0	0	0	1	0	0
10	0	0	1	0	0	0	0	1
11	0	0	0	1	1	0	0	0
12	0	0	0	0	0	1	1	0
13	0	1	0	0	1	0	0	0
14	0	0	0	0	0	1	0	1
15	1	0	1	0	0	0	0	0
16	0	1	0	0	0	1	0	1
17	0	0	0	1	0	0	0	0
18	1	0	0	0	1	0	1	0
19	0	0	1	1	0	0	0	1
20	0	1	0	0	0	1	0	0

4.1.3. Reliability of Diagnostic Assessment

The reliability of the diagnostic assessment was evaluated using the correct classification rate, which ranges from 0 to 1, with higher values indicating greater consistency in classification. In this study, the mean correct classification rate for the eight reading attributes was 0.92, yielding a Fleiss' Kappa coefficient of 0.80, indicating a high level of diagnostic reliability. This result aligns with findings from previous studies [9,48].

4.2. Analysis of Data Results from the English Reading Cognitive Diagnosis Model

4.2.1. Diagnostic Analysis of Cognitive Attribute Mastery in the Subject Group

The G-DINA model in R was employed to statistically analyze the performance of 200 subjects across eight cognitive attributes related to English reading. This analysis provided the mastery probability for each student on each attribute, as well as the group's average attribute mastery. According to **Figure 1**, in terms of overall cognitive attribute mastery probabilities, students exhibited the strongest comprehension of literal meaning at the sentence level (A2: .8185) and passage level (A3: .7891). This suggests that Chinese students tend to approach reading by first understanding the literal meaning, clarifying the basic meanings of sentences and passages, and converting second-language comprehension into familiar native-language understanding. This strategy enables them to correctly answer questions with lower cognitive demands.

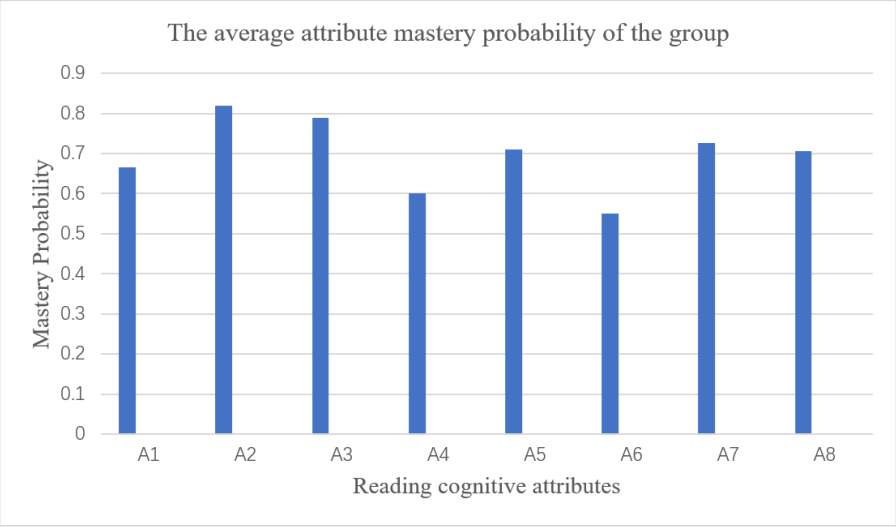

Figure 1. The overall attribute mastery of the group.

In contrast, the mastery levels for inference-related attributes, such as inferring word meaning (A4: .6001) and text elaboration inference (A6: .5509), were less satisfactory. A4 requires students to infer word meanings from context; students lacking the ability to infer from contextual information may find it difficult to correctly guess the meaning of words, even if they understand the sentence's literal meaning. Similarly, A6, which involves elaborative inference and requires deeper cognitive processing of the entire passage, poses a significant challenge for second-language learners. However, the mastery of coherence inference (A5: .7102) was relatively better. This is likely because many A5-related tasks primarily test pronoun reference inference, which involves reasoning about pronouns or demonstrative pronouns that appeared earlier in the text—a task less challenging than the other two inference-related attributes.

Students' relatively weak vocabulary recognition ability (A1: .6656) suggests that their vocabulary reserve is not extensive. This also indicates that while vocabulary size affects comprehension of sentences and passages, it is not the sole determining factor. The relatively strong abilities in information screening (A7: .7263) and information summarization (A8: .7064) suggest that students have mastered certain learning strategies, although it is possible that some may have completed these tasks using test-taking techniques. The effectiveness of such techniques in improving students' reading abilities, however, remains a subject of debate.

The overall attribute mastery analysis reveals that students struggle with higher-level cognitive attributes, while they demonstrate better mastery of lower-level cognitive attributes. This suggests that vocabulary and grammar remain the focus of instruction. Students have a

solid foundation in these areas, allowing them to achieve basic comprehension, but their deep understanding of more complex texts remains weak. Therefore, based on the group's average mastery, attributes A4 and A6 should be prioritized in teaching, with targeted interventions aimed at enhancing students' capabilities in these areas.

The study indicates that the students' mastery probabilities for various cognitive attributes are generally strong; with the exception of A6, all attributes have a mastery probability above .65. Additionally, 58% of the subjects achieved a correct answer rate above 75%. While this reflects that students' reading skills are well-developed, it also suggests that the test difficulty may have been insufficient. As noted by Zhou Shen ([49], p. 78), "test difficulty is usually defined as the correct answer rate of a particular group of subjects for a given item."

4.2.2. Diagnostic Analysis of Cognitive Attribute Mastery in Individual Subjects

The G-DINA cognitive diagnosis model provides detailed mastery probabilities for individual cognitive attributes, enabling personalized assessments for each subject. For instance, as illustrated in **Figure 2**, Subject 120 (ID 120) exhibits significantly lower mastery probabilities for attributes A4 and A6 compared to other attributes. This suggests a relative weakness in reasoning abilities, although the student demonstrates more balanced skills in recognition, comprehension, and analysis, resulting in strong overall reading proficiency.

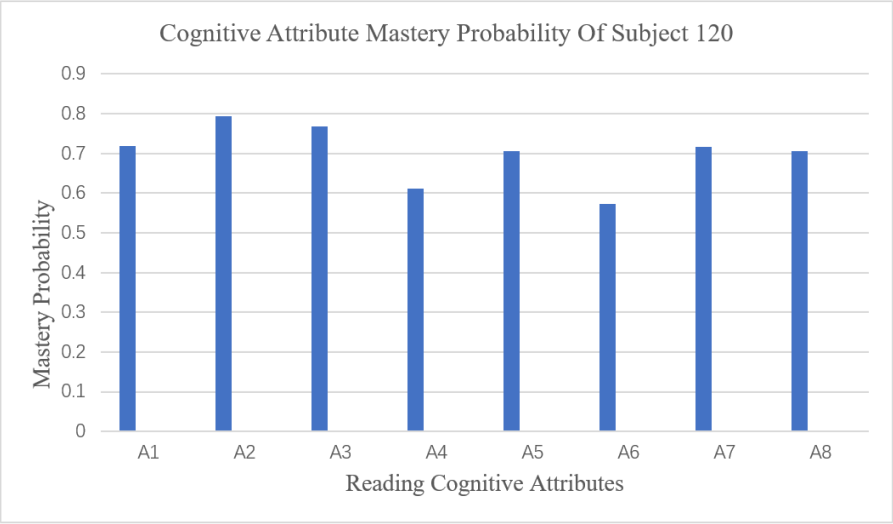

Figure 2. Cognitive attribute mastery of Subject 120.

It is crucial to recognize that different cognitive attributes are required for answering different questions correctly. Consequently, subjects with the same correct answer rate may show distinct attribute mastery profiles, a point also highlighted in the study by Mirzaei et al. [50]. For example, this study examined Subjects 18 (ID18), 32 (ID32), and 95 (ID95), all of whom had a correct answer rate of 75%. Despite this, their cognitive attribute mastery probabilities varied significantly, as detailed in **Figure 3**.

Subject 18's mastery profile closely mirrors the group's overall mastery level, with weaker performance in inferring word meaning (A4) and text elaboration inference (A6), while demonstrating stronger comprehension abilities (A2, A3). However, vocabulary knowledge (A1) still requires enhancement. Subject 32 displays a relatively balanced mastery profile, with probabilities for all eight attributes hovering around .75, indicating no significant weaknesses in reading skills and an overall above-average level. In contrast, Subject 95 shows strong performance in vocabulary recognition (A1) and comprehension of sentence and text meaning (A2, A3), but weaker abilities in text coherence inference (A6) and information summarization (A8). This student would benefit from further developing reading-related knowledge and practicing summarizing the main ideas of texts.

The average mastery probabilities indicate that these

three students share common weaknesses in higher-level cognitive attributes, such as A4, A6, and A8, while demonstrating stronger mastery of lower-level attributes. This underscores the utility of cognitive diagnosis in accurately reflecting individual differences among students with similar overall scores, thus helping identify specific challenges in their reading skills.

The personalized diagnostic information provided by cognitive diagnosis is invaluable for teachers, enabling them to better understand students' strengths and weaknesses in reading. It also helps students gain a clearer understanding of their current learning status. In reading instruction, it is essential not to rely solely on test scores for classifying or guiding students' reading abilities. Instead, educators should consider the individualized differences in students' mastery of reading skills and implement targeted remedial measures tailored to each student, ensuring more effective outcomes.

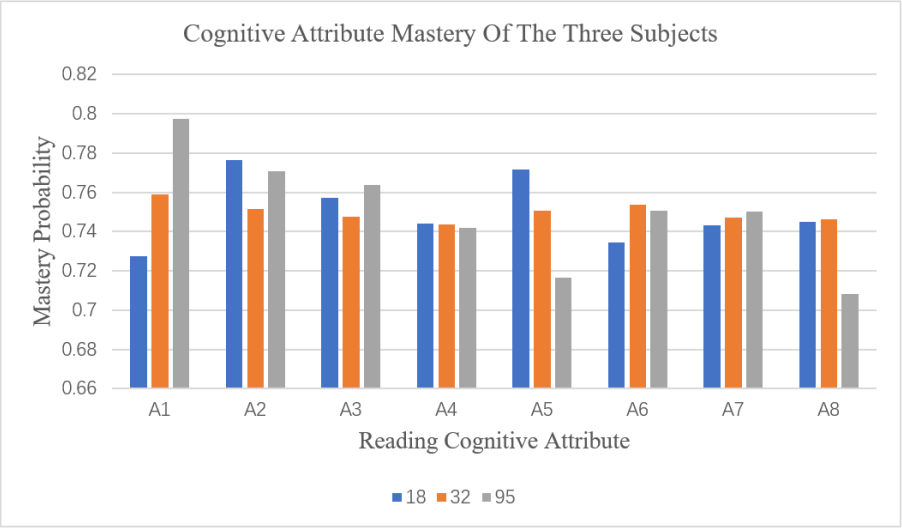

Figure 3. Cognitive attribute mastery probability of the three subjects.

4.3. Feedback

4.3.1. Individual Student Diagnostic Performance Report

Based on the diagnostic results derived from the G-DINA model, personalized reading test performance reports were generated. These reports are organized into two primary sections: the student's mastery status and a performance analysis, each accompanied by detailed remedial recommendations. The reports provide students with multidimensional, detailed, and personalized feedback. In the "My Mastery Status" section, students can assess their overall reading proficiency, gauge their mastery of various reading skills, and compare their performance with the group average. This helps them identify their strengths and weaknesses in reading. The "My Performance Analysis" section allows students to see the proficiency levels they have attained according to the established scale, understand how to interpret their current skill levels, and determine the areas they should focus on for future learning. All diagnostic feedback is generated within one week of the test, significantly reducing the manual production time associated with traditional diagnostic feedback. This timely delivery enhances the alignment between assessment and learning, demonstrating the practical value of cognitive diagnostics.

4.3.2. Survey Results on Students' Evaluation of the Reading Diagnostic Report

A survey was conducted to further explore students' attitudes toward the diagnostic report and their acceptance of the content, particularly regarding the probabilities of skill mastery presented in the report. A total of 189 students who received the reading diagnostic report participated in the survey, yielding an effective response rate of 94%. Concerning the content and layout of the DF report,

76% of students indicated that they liked or very much liked the presentation. It lists the information that over 90% of students deemed necessary for inclusion in the diagnostic report, such as personal total scores, mastery of the eight reading skills, an analysis of their responses, and learning suggestions. Among these, the analysis of students' responses and learning suggestions (M = 4.308) and mastery of reading skills (M = 4.295) were considered the most essential content to include. Regarding the acceptance of the mastery probabilities for the eight reading attributes, over 82% of students agreed with the assessment of their mastery probabilities. Moreover, more than 86% of respondents believed that the DF report helped them understand their strengths and weaknesses, thereby aiding in their further improvement.

The survey concluded with two open-ended questions. The first question asked students for their overall impressions of the DF report and invited them to list its strengths and weaknesses. Most students provided very positive feedback and expressed high levels of satisfaction, frequently using phrases such as "very good," "very clear," "very intuitive," and "highly visualized." Many also stated their intention to follow the remedial learning suggestions to enhance their performance. However, some students requested more detailed explanations of the content presented in the report. The second question asked, "Besides the information currently presented in the report, what other content would you like to see included?" Ninety-five percent of students responded that the current content was sufficient and did not require additional information. Fewer than 4% of students suggested including a comprehensive analysis of other skills such as listening, writing, and translation, while a few others proposed adding explanations for incorrect answers.

5. Discussion

First, the eight reading attributes identified in the China's Standards of English Language Ability (CSE) effectively reflect students' reading skills, providing a robust standard for the subsequent determination of reading attributes. Previous literature indicates that the confirmation of reading attributes has been a focal point of debate among scholars. The CSE offers a new perspective on defining these attributes by considering various dimensions in light of China's unique context and needs. This approach not only enhances the reliability of constructing a cognitive diagnostic model for English reading but also aligns with the specific characteristics of the target population.

Secondly, the personalized performance reports generated from the diagnostic results of the cognitive diagnostic model provide a clear and detailed analysis of students' strengths and weaknesses in reading, along with tailored suggestions for their future learning. The application of the cognitive diagnostic model in English reading extends beyond previous research, which primarily focused on teachers' understanding and analysis of students' reading performance. These personalized reports represent a synthesis of the cognitive diagnostic model and the actual needs of students, offering a more intuitive deepening of their self-awareness regarding their reading abilities and facilitating targeted remedial strategies.

6. Conclusions

This study employed the G-DINA cognitive diagnosis model to construct a cognitive diagnosis framework for English reading assessments, identifying eight key cognitive attributes that influence reading proficiency. Using appropriate statistical methods, the study generated multi-level diagnostic information for both groups and individuals, producing personalized reading diagnostic feedback. Furthermore, the study investigated students' perceptions and evaluations of the diagnostic reports. The findings have several implications for English reading instruction: the diagnostic information can guide educational administrators and teachers in refining the focus and complexity of language skill development and optimizing the current curriculum. Teachers can incorporate these cognitive attributes into their reading instruction, design targeted exercises for each attribute, and develop tailored intervention strategies for students of varying proficiency levels. Additionally, students can use the personalized diagnostic feedback to adjust their self-directed learning focus and address challenges more effectively.

Although this study provides an in-depth analysis of cognitive attributes related to English reading, several limitations need to be acknowledged. First, the exclusion criteria may have introduced sample selection bias. Specifically, students with special educational needs and those who did not complete the test or provide complete data were excluded. While these criteria ensured the integrity and validity of the data, they also limited the representativeness of the sample, potentially affecting the generalizability of the findings. Second, the final sample size of 189 students was relatively small. Although sufficient for the scope of the study, this sample may not fully represent a broader student population, which could impact the applicability of the results to other groups. Third, the study's definition of cognitive attributes did not clearly differentiate between skills and strategies, and it did not consider metacognitive skills. While the exclusion criteria removed certain confounding factors, they did not capture all cognitive variables that might influence reading ability. Future research should refine the conceptualization of cognitive attributes and employ additional methods, such as textual analysis, to provide a more comprehensive understanding of test takers' reading abilities and improve cognitive diagnostic outcomes.

Author Contributions

All authors have made a substantial, direct, and intellectual contribution to the work, including but not limited to Conceptualization, Methodology, Investigation, Formal analysis, Writing—Original Draft, and Writing—Review & Editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

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Informed Consent Statement

All participants provided informed consent before participating in the study. The anonymity and confidentiality of the participants were guaranteed, and participation was completely voluntary.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflict of interest.

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