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# Research on Technical Support and Application Strategies for Enhancing Youth Digital Security Literacy in the Smart Media Era

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**SUMMARY:** *The cognitive diagnostic assessment and constructed digital safety literacy assessment framework is based on the following five aspects: Information Identification (IJ), Self-Protection (SP), Safe Communication (SC), Legal Compliance (LC) and Safety Emergency Response (SE). With the help of the seq-GDINA multi-level scoring model, an empirical investigation about college students was made. Multidimensional improvement paths include educational intervention measures, cooperation between school and family, community and teacher, policy guarantee and other methods. Diagnostic results show that only 13.50% (42 people) can grasp all attributes well. Among all the students, nearly half have the deficiency in LC and SE attributes. And SC is in the worst condition, whose low-score part mastery probability is as low as 20.29%. Comparison of modeling shows that seq-GDINA is superior to the conventional model and the neural network model with advantages in ACC (0.811), RMSE (0.377) and F1 score (0.818). Experimental teaching also verifies the effectiveness of the improvement path, and more than 85% of the students think their level has been improved in general.*

***KEYWORDS:*** *Digital safety literacy; Cognitive diagnosis; Q matrix; DINA model; seq-GDINA*

## 1 Introduction

They are now deeply embedded into our daily lives. They affect online education as well as entertainment, smart homes, and even smart cities. For teenagers, having high levels of digital literacy would be important both to become a part of the future world and to grow up and study efficiently in the information age we are living in today [1-3].

In terms of the scope, digital literacy can be defined as an ability of a person to use digital environment in order to find out, understand, evaluate, create, and communicate information [4]. Digital literacy covers different aspects, ranging from computer skills, information literacy and cybersecurity, to digital content creation, and even digital etiquette [5, 6]. In order to develop digital literacy of a teenager, it is very important to provide him/her with necessary skills in working with digital technologies. This can be achieved by giving many possibilities to work with various digital devices and programs, like computers, smartphones, tablets, and other software at home or school, with increasing digital security literacy using technical support [7-11].

Technical support may be facilitated by means of personalized learning systems that offer individualized educational content [12]. Personalized learning systems suggest appropriate educational content and activities in line with learners' progress and skills, thus improving their

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performance [13, 14]. Technology application can help to provide engaging and immersive learning opportunities to young people using virtual reality and augmented reality [15, 16]. Besides, technology application encourages students' innovative thinking and problem-solving skills [17]. By participating in programming lessons and robotic design classes, young people will gain knowledge about applying technological solutions to problems and develop their innovation and creativity [18, 19]. Cybersecurity education is an integral part of developing youth digital literacy [20]. Protection of personal information and preventing cyber frauds are especially significant aspects in the digital environment. Young people will receive relevant knowledge on how to act responsibly and securely in the online world [21-23].

Reference [24] uses literature review as its research design method, which suggests that most adolescents know how to utilize digital tools like smartphones. Nevertheless, there is still considerable difference in digital literacy in terms of the effective utilization of technology for productive purposes. This research highlights the importance of providing educational and social environment support in improving the digital literacy of adolescents. Literature [25] seeks to develop the digital literacy and raise the awareness of adolescent mental health issues. It has successfully used experimental results to showcase the effectiveness of interdisciplinary education intervention in helping adolescents develop vital digital capabilities and emotional strength in the age of social media. Literature [26] examines the significance of technological support in developing digital literacy among youth and reveals some useful information on the efficiency of current technological interventions. In addition, it provides a pathway for developing the digital literacy of youth and solving the associated issues like privacy threats, overreliance, and digital literacy disparity. Literature [27] discusses the development of youth digital literacy through teachers' and libraries' contribution. It advocates the adoption of an innovative constructivist learning theory to overcome the challenges facing the digital world. Literature [28] discusses the development of digital literacy and teachers' contribution in the formation of students' personality in smart media age. This is evident from observation and interview results where digital literacy is embedded into learning using digital media while teachers influence the formation of the character of their students through digital ethics. Literature [29] examines the contributions of teachers towards enhancing the digital literacy of students, showing that the success of the process relies heavily on their capability, innovation, and leadership. Literature [30] focuses on embedding character education into the digital literacy of youths. However, this study shows that there is little success in achieving this objective because of insufficient time. Literature [31] highlights the growing debate around the implications of the extensive use of technology by youths in the age of smart media considering the vulnerability of adolescents to technology and its contents. According to Reference [32], technology has slowly evolved to change online forums into important social settings for teenagers, resulting in an environment of possibilities and difficulties, particularly concerning the significance of technology in improving adolescent digital literacy. Research [33] explores barriers to improving the digital literacy skills of adolescents, offers solutions to the problem, and provides recommendations for further enhancement of these skills. Research [34] investigates the effect of digital literacy on the risk of becoming addicted to gaming. Based on the analysis conducted with the help of questionnaires, the research reveals that adolescents with increased levels of digital literacy tend not to be at risk of becoming addicted to gaming. It is stated that promoting digital literacy skills in adolescents is necessary for maximizing the benefits of media and minimizing the harm caused by technological devices. Research [35] offers a systemic review of the existing literature on the relationship between resilience, digital literacy, and wellbeing in adolescents who experience negative online interactions, investigating the interconnection between these aspects. It is indicated that experiencing negative online interactions is damaging to the wellbeing of adolescents but is a crucial pre-requisite for building online resilience.

In order to make the transition from "generalized assessment" to "precise diagnosis," this research takes advantage of the Cognitive Diagnostic Assessment (CDA) framework to conduct an in-depth analysis of the status of mastery of micro-level cognitive attributes associated with digital safety literacy in adolescents. First, this paper will expound on the theoretical basis and basic models of cognitive diagnostics. With the aid of Q-matrix theory, the paper constructs the mapping relation between examination questions and objective cognitive attributes such as "information recognition" and "self-protection." Next, this paper introduces the DINA model and its advanced versions (G-DINA and seq-GDINA), highlighting their diagnostic advantages in evaluating multi-attribute, hierarchical, and non-compensatory structures of digital safety literacy in adolescents. Eventually, the seq-GDINA model, which can cope with multi-stage logical reasoning procedures, is adopted as the key diagnostic tool. Based on the theoretical foundation above and combined with the risk features and policy requirements of the intelligent media age, this paper designs a three-level assessment framework for adolescent digital safety literacy, which includes five aspects: "Information Recognition and Evaluation," "Self-Protection in Digital Environment," "Safe Interaction and Cooperation," "Digital Legal Compliance and Digital Ethics," and "Digital Safety Emergency Response and Problem Solving."

# 2 Diagnostic Study on Adolescents' Digital Safety Literacy Based on the DINA Model

In the age of smart media, adolescents are increasingly confronted with digital information and virtual spaces. The digital safety literacy level of adolescents is of direct significance to their personal privacy security and behavior standards as well as the development of the cybersecurity environment. In this chapter, the main research tool is the DINA cognitive diagnosis model and seq-GDINA multi-level grading system, which builds up an objective cognitive diagnostic evaluation framework to assess adolescent digital safety literacy scientifically and practically.

## 2.1 Q Matrix

Cognitive Diagnosis Assessment (CDA) establishes a correspondence between the external response style and the internal processing process of students, where different developmental levels in each domain are expressed by attribute mastery pattern and probability. Thus, CDA provides more detailed diagnoses that can distinguish individual differences among students with similar scores through case-by-case analysis.

For cognitive diagnosis, Q matrix provides the basis as it clearly states what cognitive attribute is measured in every item of the test.

Thus, the Q matrix establishes a connection between items and cognitive attributes. It comprises binary elements, including 0 and 1 where 1 means that the cognitive attribute is measured and 0 that it is not measured. The accurate establishment of the relation between the test item and measurement attributes affects the efficiency of cognitive diagnostic tests. The establishment of a correct Q matrix is vital to ensure proper testing outcomes. The development of the Q matrix and its corresponding items allows completing cognitive diagnostic test papers.

A study has shown that using the wrong Q matrix can increase parameter estimation error, decrease the diagnostic accuracy of candidates, and cause the model to be unidentifiable. As such, having a right Q matrix is important. With the advent of cognitive diagnosis, there have been several Q-matrix correction techniques developed. There is a new two-stage Q-matrix correction technique developed by Wang Daxun and Gao Xuliang. The new method shows less sensitivity to sample sizes and Q-matrix errors while keeping its accuracy at a high level despite the small sample size. The corrected Q matrix shows better data fit. The appearance of Q-matrix correction methods is extremely necessary in increasing the accuracy of cognitive diagnostic testing. The Q-matrix acts as the link between cognitive psychology and psychometrics. Table 1 below shows a Q matrix example.

*Table 1: Demonstration of Q Matrix*

| Item | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| 2 | 1 | 1 | 1 | 0 | 1 | 1 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 0 | 1 | 1 | 0 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 |
| … | … | … | … | … | … | … |
| 20 | 1 | 1 | 1 | 1 | 1 | 0 |

Table 1 provides the Q-matrix (20x6), containing 20 questions and six cognitive attributes. Consider that for the first test question, the attributes A1, A2, and A5 are assessed; however, attributes A3, A4, and A6 are not assessed. The remaining test items follow this pattern. A value of 1 indicates that a cognitive attribute is assessed, while 0 indicates that it is not assessed.

## 2.2 Cognitive Diagnostic Model

### 2.2.1 DINA Cognitive Diagnostic Model

The DINA cognitive diagnostic model is also known as the Deterministic Input, Noise, and Gate model. “Deterministic input” refers to the certainty that if a subject possesses a certain attribute, they can correctly apply that attribute to solve corresponding problems, emphasizing the certainty of the input process. “Noise” refers to errors and guesswork made by subjects during problem-solving, as well as interference factors present in the output process. The DINA cognitive diagnostic model is a typical discrete cognitive diagnostic model suitable for cognitive diagnosis in tests with binary scoring items. Compared to other cognitive diagnostic models, the DINA model offers better parameter interpretability, and its complexity remains unaffected by the number of attributes. Student knowledge point mastery vector: Denoted as $\alpha_i = \{\alpha_{i1}, \alpha_{i2} ... \alpha_{ik}\}$ represents the knowledge point mastery of the $i$ th student, where $k$ denotes the total number of relevant attributes. $\alpha_{ik} = 1$ indicates the student has mastered the knowledge point, while $\alpha_{ik} = 0$ indicates non-mastery.

The DINA cognitive diagnostic model utilizes multiple matrices. Let $q_{ik}$ denote whether knowledge point $k$ is required to correctly answer question $j$ , where $q_{jk} = 1$ indicates requirement and $q_{jk} = 0$ indicates no requirement. The matrix $Q$ formed by $q_{jk}$ can be regarded as a cognitive design matrix, explicitly detailing the cognitive information for each item.

The mathematical formula for the DINA cognitive diagnostic model is:

$$P = (Y_{ij} = 1 | a_i) = (1 - s_j)^{nij} g_j^{1-nij} \tag{1}$$

$$n_{jk} = \prod^{k} \alpha_{ik}^{qk} \tag{2}$$

$nij$ denotes the relationship between subject $i$ and item $j$. For example, $P(Y_{ij}) = 1$ indicates that subject $i$ answered item $j$ correctly, represented by 1, while an incorrect answer is denoted by 0.

$n_{ij} = 1$ represents the student's potential response to the item, indicating the student answered correctly—i.e., mastered all knowledge points covered by the item. $n_{ij} = 0$ indicates an incorrect response, meaning the student failed to master at least one knowledge point within the item. $k = 1, 2...k$ denotes the number of attributes. $g_j$ represents the guessing parameter, $s_j$ denotes the error parameter, $q_{jk}$ indicates whether item $j$ assesses attribute $k$, $a_{jk}$ signifies whether examinee $i$ has mastered attribute $k$, and $n_{ij}$ reflects whether examinee $i$ has mastered all assessed attributes. Therefore, the probability of a subject answering a question correctly is also related to the subject's own knowledge state.

The architecture of DINA cognitive diagnosis is comparatively less complicated. It offers an explanation of student responses in a simple way and with comprehensible parameters that are easy to manage. The level of complexity of the DINA model does not depend on the number of attributes. This means that regardless of how many knowledge points are evaluated in the test, the DINA model remains simple and efficient. This model is non-compensatory and thus, students are required to acquire all attributes in order to respond correctly to a question since acquiring one or more of them will not enable them to get it right.

### 2.2.2 GDINA Model

On the other hand, the G-DINA model is an improvement of the DINA model and facilitates the process of estimating cognitive attributes. The assumptions of G-DINA are that the mastery of each attribute evaluated by a particular question affects the response probability. In other words, attribute interactions affect response accuracy. There are two main features of the G-DINA model: Second, saturation—it incorporates not only parameters for individual attributes but also parameters reflecting interactions among multiple attributes. Its mathematical expression is:

$$P(X_{ij} = 1 \mid a*_{lj}) = \&_{j0} + \sum_{k=1}^{K^*j} \&_{jkalk} + \sum_{k'=k+1}^{K^*j} \sum_{k=1}^{K^*j-l} \&_{jkk'alkalk'} + \cdots + \&_{j12\ldots K*j} \prod_{k=1}^{K*j} a_{lk} \tag{3}$$

The probability of correctly answering a test item is the cumulative probability of getting it right under different levels of mastery of its attributes. $P(X_{ij} = I \mid a*lk)$ denotes the probability that a subject answers item j correctly; $\&_{j0}$ denotes the probability of a correct response when the examinee does not master any attribute measured by the item, i.e., the probability of guessing correctly, with $\&_{j0} \geq 0$; $\&_{jk}$ represents the contribution to the probability of answering item j correctly when the examinee masters a single attribute $a_{lk}$; $\&_{jkk}$ represents the interaction effect of the subject's mastery of attributes $a_{lk}$ and $a_{lk}$ on the correct response rate for item j; $\&_{j12\ldots K*j}$ denotes the interaction effect of mastery over all attributes measured by item i on the correct response rate.

### 2.2.3 seq-GDINA Model

The seq-GDINA model, also known as the sequential process model, is a multi-level scoring model optimized from the G-DINA model. It primarily emphasizes the sequence of attributes involved in the problem-solving process. Unlike other two-level scoring models, this model not only considers whether a test item involves multiple attributes but also assigns a sequential order to the attributes involved in problem-solving. This avoids the tendency of two-level scoring models to push participants' scores toward the extremes of zero or full marks. The model employs the G-DINA model as the link function for estimating each distinct test item. A brief overview follows:

If the subject's attribute mastery model is $\alpha_c$, then the probability of correctly answering test item j for category h is $S_j(h \mid \alpha_c)$. The calculation formula is as follows:

$$S_j(h \mid \alpha_c) = \begin{cases} 1, & if \quad h = 0 \\ 0, & if \quad h = H_j + 1 \end{cases} \tag{4}$$

where $H_j$ is the number of categories for item j, the probability formula for a subject scoring h on item j is as follows:

$$p(X_j = h \mid \alpha_c) = [1 - S_j(h+1 \mid \alpha_c)] \prod_{x=0}^{h} S_j(x \mid \alpha_c) \tag{5}$$

It follows that the total probability of subjects with different attribute mastery patterns obtaining different scores on item j is l.

$$\sum_{h=0}^{H_j} p(X_j = h \mid \alpha_c) = 1 \forall c \tag{6}$$

The model can be applied not only to diagnose binary-scoring question types such as multiple-choice and fill-in-the-blank questions, but also to diagnose multi-level scoring question types involving sequential logical reasoning processes, such as proof questions and problem-solving questions. The seq-GDINA model addresses the limitations of two-level scoring models in educational assessment for question types like multi-step computational problems. Therefore, this study employs the seq-GDINA model to conduct a cognitive diagnostic study on adolescents' digital safety literacy.

## 2.3 Establishing a Digital Safety Literacy Assessment System for Youth

Following a brief overview of cognitive diagnostic models, this section focuses on constructing an assessment system for youth digital safety literacy to further ground theoretical frameworks in practical educational contexts. Through the incorporation of domestic and international authoritative criteria along with specific policy demands, we are able to create a multi-faceted set of indicators that include information awareness, self-protection, safety cooperation, law compliance, and emergency handling.

The existing measurement of youth digital literacy mainly focuses on general capabilities such as information collection, tool usage, and creation. Safety capability has not been well integrated into the evaluation process, and lacks a science-based, specialized, and operational standard that can reflect the real level of safety literacy among young people. This research attempts to refer to some key features of safety literacy that have been identified in the EU's DigComp and UNESCO's Global Digital Competence Framework. Meanwhile, the research takes full consideration of the policy orientation and local practice in China under relevant policies and regulations like the Cybersecurity Law and Online Protection Regulation for Children. Following the standards of scientificity, development relevance, and measurability, the research narrows down the focus to the safety dimension in the comprehensive evaluation of digital literacy. Consequently, an expert system of assessment indicators regarding youth digital safety literacy is established in this study. This indicator system makes comprehensive measurement on adolescents' ability to cope with risks and behavioral standards in the digital era through five aspects, which include information recognition, self-protection, secure cooperation, law adherence, and emergency management. The youth digital safety literacy assessment indicators are listed in Table 2.

*Table 2: Evaluation Indicators for Digital Safety Literacy of Teenagers*

| Primary indicator | Secondary indicator | Tertiary indicator |
|---|---|---|
| Information Recognition and Judgment Ability | IJ1: Judgment of Information Authenticity | C1: Identifying false information and online rumors |
| | | C2: Judging the reliability and authority of the source of information |
| | IJ2: Privacy Information Identification and Protection | C3: Identifying and consciously protecting personal sensitive information |
| | | C4: Judging the context and risks of information sharing |
| Self-Protection in the Digital Environment | SP1: Account and Password Security | C5: Setting strong passwords and changing them regularly |
| | | C6: Using dual authentication and other enhanced security measures |
| | SP2: Privacy Settings and Management | C7: Reasonably setting privacy permissions for social platforms |
| | | C8: Managing the scope of personal data sharing |
| | SP3: Anti-fraud and Anti-invasion Capabilities | C9: Identifying common online fraud methods |
| | | C10: Responding to online bullying and harmful information |
| Secure Communication and Collaboration | SC1: Safe Communication Habits | C11: Using encrypted communication tools |
| | | C12: Distinguishing and avoiding online phishing and other fraudulent behaviors |
| | SC2: Security Awareness in Resource Sharing | C13: Safely sharing files and links |
| | | C14: Identifying and avoiding the spread of malware and viruses |
| Legal Compliance and Digital Ethics | LC1: Cognition of Digital Behavior Legality | C15: Understanding relevant laws and regulations on cybersecurity |
| | | C16: Identifying and avoiding online illegal activities |
| | LC2: Digital Ethics and Responsibility | C17: Respecting others' privacy and intellectual property rights |
| | | C18: Practicing honesty and responsible behavior in the digital environment |
| Safety Emergency and Problem Solving | SE1: Security Incident Response Capability | C19: Identifying device abnormalities and security threats |
| | | C20: Taking basic response measures (such as disconnecting the network, reporting for repair, reporting, etc.) |
| | SE2: Ability to Use Security Tools | C21: Using antivirus software, firewalls, and other security tools |
| | | C22: Mastering basic data backup and recovery methods |

The indicator structure consists of five primary indicators, which are: information recognition and evaluation capability, digital environment self-protection capability, communication and cooperation security capability, digital legal compliance and ethical awareness, and digital security incident handling and problem-solving capability. The five aspects have a sequential relationship: from the basic information recognition and evaluation capability, to the digital environment self-protection capability, then to the communication and cooperation security capability, to digital legal compliance and ethical awareness, and finally to the digital security incident handling and problem-solving capability. In summary, the indicator system covers all aspects of digital security literacy in a circular manner, covering the entire process of “information recognition, self-protection, practice, regulation, and response.” Each primary indicator is decomposed into secondary indicators and tertiary indicators, totaling 11 secondary indicators and 22 tertiary indicators. The indicators can be used to transform the abstract concept of digital security literacy into specific, measurable, and operational behavior standards, including "recognizing phishing activities," "using password management strategies," "appropriately managing privacy permissions," and "handling cyberbullying."

# 3 Empirical Study on Diagnosing Adolescents' Digital Safety Literacy Based on the seq-GDINA Framework

Based on the existing model and Q-matrix of youth digital safety literacy, this chapter carries out empirical studies to correctly reveal the micro-cognitive structure of youth digital safety literacy by means of cognitive diagnostic tests. The study utilizes seq-GDINA model to analyze empirical data and systematically evaluates the performance of adolescents in five attributes such as information identification, self-protection, safety collaboration, legal compliance, and emergency response from dimensions like attribute mastery patterns, score-attribute relations, and multi-model performance comparisons, providing evidence for realizing precise education through diagnosis and intervention.

## 3.1 Q Matrix-Based Test Item Attribute Detection

This chapter will develop cognitive diagnostic assessments for adolescents based on their actual digital life experiences and acquire real data. By applying cognitive diagnostic models, granular evaluation of youth digital safety literacy will be realized in this chapter, which can help understand their strengths and weaknesses in terms of cognitive structure, so as to realize precise digital safety education intervention.

### 3.1.1 Test Description Based on Youth Digital Safety Literacy

According to the assessment framework for adolescent digital safety literacy, this research designed test questions as diagnostic questions that could examine adolescents' knowledge regarding digital safety literacy. There will be 30 test questions with 5 simulated scenarios. The test will provide a comprehensive diagnosis through a series of simulated scenarios based on everyday, realistic, complicated digital activities that adolescents may encounter. They include:
• Celebrity product marketing and fan relationship building activities; Online gaming 'group activities' and financial transactions; College 'confessions' wall and social interaction; Online learning resources exchange and technical help-seeking; Management and settings of home smart devices. Each scenario consists of six questions, amounting to a total score of 100 points. Through a diagnostic analysis of students' answers to such complicated and interrelated questions, their digital safety cognitive characteristics can be diagnosed accurately.

### 3.1.2 Constructing the Q Matrix

For further validation of the validity of the 30-item cognitive assessment, we have recruited 10 education experts as follows: three cybersecurity education researchers; four senior secondary school teachers teaching Information Technology/Ethics and Rule of Law; two specialists in adolescent psychological development and behavioral research; and one researcher on cyber laws and policies. It will ensure that the calibration process would be professional and relevant from different aspects such as education measurement, cybersecurity, adolescent psychological development, and law regulations.

In this study, the expert judgment approach is used for the calibration of the Q matrix. In total, 10 professionals were involved in the calibration process. Once 50% of professionals calibrated a certain attribute, the attribute was confirmed to measure cognitive attribute. Agreement between the professionals' calibrations was quantified using Kendall coefficient, resulting in $w = 0.804$, $p<0.001$. It means that a high level of agreement exists between the professionals in the Q matrix calibration process. Table 3 shows the calibrated Q matrix of the YDSL Test.

*Table 3: Teenagers' Digital Safety Literacy Test Q Matrix*

| | IJ | SP | SC | LC | SE |
|---|---|---|---|---|---|
| Item1-1 | 0 | 0 | 1 | 1 | 1 |
| Item1-2 | 1 | 1 | 0 | 0 | 1 |
| Item1-3 | 1 | 0 | 1 | 1 | 0 |
| Item1-4 | 1 | 0 | 1 | 1 | 1 |
| Item1-5 | 0 | 1 | 0 | 1 | 0 |
| Item1-6 | 0 | 1 | 1 | 1 | 1 |
| Item2-1 | 1 | 1 | 0 | 0 | 0 |
| Item2-2 | 1 | 0 | 0 | 1 | 0 |
| Item2-3 | 1 | 0 | 1 | 0 | 0 |
| Item2-4 | 0 | 0 | 0 | 1 | 0 |
| Item2-5 | 1 | 1 | 0 | 0 | 1 |
| Item2-6 | 1 | 1 | 0 | 0 | 1 |
| Item3-1 | 0 | 1 | 1 | 1 | 1 |
| Item3-2 | 1 | 0 | 1 | 1 | 1 |
| Item3-3 | 0 | 0 | 1 | 0 | 1 |
| Item3-4 | 0 | 1 | 1 | 0 | 0 |
| Item3-5 | 1 | 0 | 0 | 0 | 1 |
| Item3-6 | 1 | 0 | 1 | 1 | 1 |
| Item4-1 | 1 | 1 | 1 | 0 | 1 |
| Item4-2 | 1 | 0 | 1 | 1 | 1 |
| Item4-3 | 1 | 1 | 0 | 1 | 0 |
| Item4-4 | 1 | 1 | 1 | 0 | 0 |
| Item4-5 | 1 | 1 | 1 | 0 | 0 |
| Item4-6 | 0 | 0 | 0 | 1 | 1 |
| Item5-1 | 1 | 0 | 1 | 0 | 1 |
| Item5-2 | 0 | 1 | 0 | 0 | 1 |
| Item5-3 | 1 | 1 | 1 | 1 | 1 |
| Item5-4 | 0 | 0 | 0 | 1 | 0 |
| Item5-5 | 1 | 0 | 1 | 0 | 1 |
| Item5-6 | 1 | 1 | 0 | 0 | 0 |

Through statistical analysis, it can be discovered that the cognitive characteristics are all included in the test. However, there are some differences in emphasis in some respects. For instance, "Information Identification and Judgment (IJ)" and "Safety Emergency Response and Problem Solving (SE)," which are two of the most tested cognitive characteristics, each account for 20 items and 18 items, respectively, at a coverage rate of 66.67% and 60%, demonstrating the importance of recognizing and solving information and emergencies in adolescent digital safety literacy. All in all, all cognitive characteristics are comprehensively covered, thus allowing a comprehensive analysis of examinees' ability to utilize their knowledge. In conclusion, the construction of this Q-matrix is rational and scientific.

## 3.2 Case Study on Adolescent Digital Safety Literacy Based on Cognitive Diagnostic Testing

In order to verify the reliability of the testing system and diagnose the micro-cognitive structures of the adolescents’ digital safety literacy competence, in the current study, the seq-GDINA cognitive diagnostic model in Chapter 2 will be combined with the Q-matrix of the designed test in Chapter 3 to model the actual data provided by the adolescents during the assessment. The method is able to evaluate the overall performance of the test takers as well as uncover the particularities of their competencies in each attribute in the digital safety context.

### 3.2.1 Analysis of Student Attribute Mastery Patterns

A cognitive diagnostic assessment of adolescents' digital safety literacy competency was carried out at a secondary school in May 2025 and took 60 minutes to finish. 311 eighth-grade students were involved in this test process. In total, 311 test questionnaires were released and 253 test booklets were recovered. As a result, the validity rate is 96.93%. The collected response data can be regarded as the research sample. After the test, a cognitive diagnostic analysis will be carried out based on the response data of the test takers.

The first benefit of cognitive diagnosis is its capability to evaluate the knowledge structure of an individual based on their answers. To be more specific, cognitive diagnosis evaluates individual knowledge structures using a vector of numbers from zero to one. For instance, the pattern of attribute mastery 11101 suggests that the individual has mastered the first, second, third, and fifth attributes, but has not mastered the fourth attribute. In other words, the individual has mastered "Information Identification," "Self-Protection," "Safe Collaboration," and "Emergency Response," but he/she has not mastered the "Legal Compliance" attribute. There are altogether 16 patterns of attribute mastery identified among the 311 participants. Patterns of attribute mastery among all students can be found in Table 4. Figure 1 shows the bubble chart of the top ten patterns of mastery, in which the x-axis shows the percentage of individuals in each pattern, while the size of the bubbles indicates the total percentages of all patterns.

*Table 4: The attribute mastery model that students adopt*

| Mastering Mode | Number of students | Proportion | Cumulative Proportion |
|---|---|---|---|
| 11011 | 82 | 26.37% | 26.37% |
| 11110 | 68 | 21.86% | 48.23% |
| 11111 | 42 | 13.50% | 61.74% |
| 11101 | 34 | 10.93% | 72.67% |
| 10111 | 22 | 7.07% | 79.74% |
| 11001 | 16 | 5.14% | 84.89% |
| 10011 | 12 | 3.86% | 88.75% |
| 11010 | 9 | 2.89% | 91.64% |
| 10101 | 7 | 2.25% | 93.89% |
| 01011 | 6 | 1.93% | 95.82% |
| 01101 | 5 | 1.61% | 97.43% |
| 11000 | 3 | 0.96% | 98.39% |
| 01110 | 2 | 0.64% | 99.04% |
| 10010 | 1 | 0.32% | 99.36% |
| 10001 | 1 | 0.32% | 99.68% |
| 01010 | 1 | 0.32% | 100.00% |

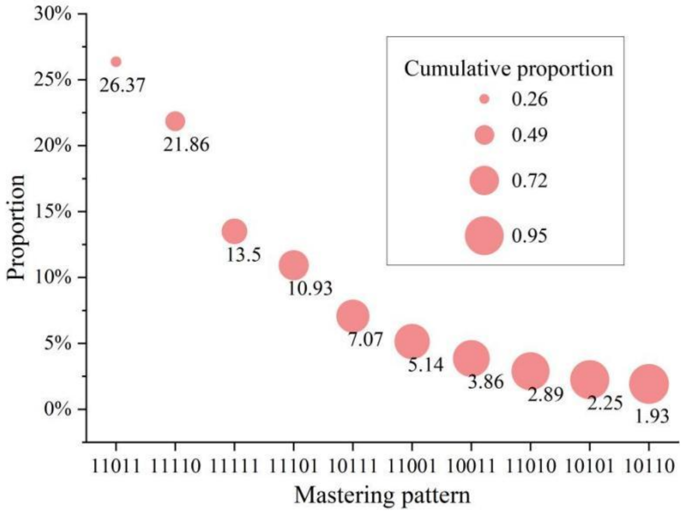


*Figure 1: Bubble chart of the top 10 mastering modes*

As a consequence of employing the seq-GDINA approach in the present study, 16 attribute mastery patterns emerged. As can be observed, the use of cognitive diagnostics has the advantage of identifying micro-heterogeneity of cognitive structures in terms of mastery. In this case, although the structure is diverse, there is a tendency for concentration in the level of mastery of the subjects. The most common top 10 mastery patterns from 11011 to 01011 altogether occupy up to 95.82%. This suggests that it would be enough to summarize the cognitive states of most participants with the help of these 10 mastery patterns.

Among these 961 students, only 13.50% managed to attain the highest level of cognitive mastery by having mastered all the five attributes. As a whole, most participants demonstrated a lower level of cognition by failing to master at least one attribute. Particularly, the first and second most common patterns of cognition were pattern 11011 and pattern 11110, with shares of 26.37% and 21.86%, correspondingly, which altogether make up 48.23%. These numbers suggest that the major weaknesses typical of contemporary adolescents include low awareness regarding legal compliance and digital etiquette, along with poor emergency response and problem-solving skills. Another common mastery pattern is pattern 11101 (absence of mastery of SC).

### 3.2.2 Relationship Between Scores and Attribute Mastery

The relationship between the total scores and mastery of the attributes can be seen from Table 5 and Figure 2.

From the graph, it can be said that when total scores increase, the mastery rates of the attributes also increase. This means that there exists a significant positive correlation between test scores and mastery rates. In particular, in the range 90-100, the mastery rates for all attributes were more than 90% where the mastery rate for Information Identification and Judgment was 100% implying that high scoring students performed very well in the identification of information. Nonetheless, there was great variation in mastery rates across the attributes. In all the ranges, the mastery rate of SC was low. In the range 90-100, it was only 92.27% making it lower than others. Furthermore, in the low score range (0-40), its rate dropped to 20.29% making it lower than others which means this attribute is one that students tend to lack. Also, LC and SE were seen to improve in the medium score range (40-70 points). This means that these two attributes still require much improvement as scores increase. SP and IJ attributes had high mastery rates in the medium to high score range (more than 70 points).

*Table 5: The relationship between students' scores and their mastery of attributes*

| Score range | Mastering probability / % | | | | |
|---|---|---|---|---|---|
| | IJ | SP | SC | LC | SE |
| 0-40 | 45.18 | 39.14 | 20.29 | 34.63 | 29.12 |
| 40-50 | 80.18 | 64.24 | 44.34 | 51.71 | 51.69 |
| 50-60 | 86.28 | 74.08 | 51.17 | 65.34 | 66.71 |
| 60-70 | 93.16 | 80.66 | 63.57 | 73.79 | 72.52 |
| 70-80 | 96.26 | 86.76 | 72.45 | 83.32 | 80.09 |
| 80-90 | 98.78 | 93.18 | 80.56 | 90.53 | 85.76 |
| 90-100 | 100 | 97.82 | 92.27 | 95.94 | 94.41 |

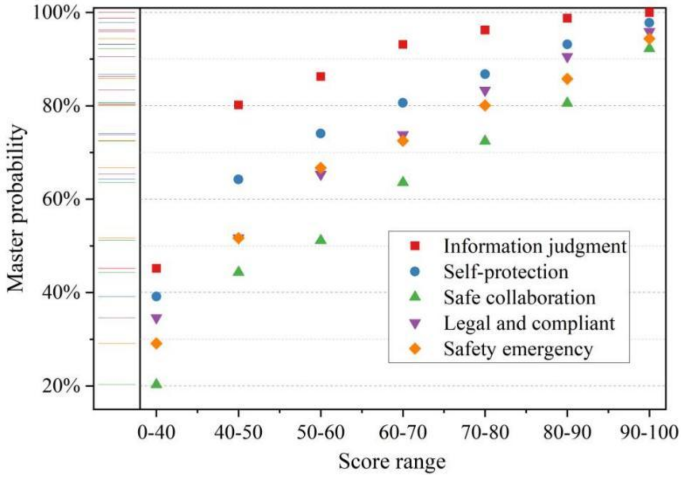


*Figure 2: Score and attribute mastery relationship*

## 3.3 Baseline Model Comparison Experiments

In order to verify the diagnostic ability of the seq-GDINA model compared with other models, a baseline experiment was conducted to compare the seq-GDINA model with existing mainstream cognitive diagnostic models. Through experiments with different proportions of data sets, the effectiveness of the seq-GDINA model compared with other cognitive diagnostic models (IRT, DINA, and GDINA models) will be tested and verified on multiple aspects, including prediction, error control, and full classification capabilities.

### 3.3.1 Experimental Preparation

(1) Dataset◁BR/▷The dataset that was used in our experiment was collected using real-world data from a "Youth Digital Safety Literacy Diagnostic Assessment," which we created ourselves. This dataset consists of 1,827 valid responses of students studying at a secondary school. Each data sample contains information about the student's grade on each problem and its attribute mastery pattern label.

(2) Baseline Models

Seven baseline models were chosen for comparing the results of our experiments with the seq-GDINA approach: IRT, MIRT, Neural CD, IKNCD, NACD, DINA, and GDINA. The description of each model's algorithms follows.

IRT: The individual ability levels of examinees are represented as continuous latent variables.

MIRT: The multi-dimensional ability levels of students are considered as vectors.

Neural CD: It uses neural networks instead of designing the function manually to increase the diagnostic capacity.

IKNCD: Knowledge point importance is taken into account to make better diagnostics; the importance is defined according to the frequency of use.

NACD: It combines various new aspects to predict how students would perform using the text of questions and relations between knowledge points.

### 3.3.2 Performance Comparison Analysis

In this part, seq-GDINA is trained and tested along with other seven baseline methods with different percentages of training set size (60%, 70%, 80%, and 90%). The performance scores of these eight methods were evaluated based on three performance measures: ACC, RMSE, and F1 score. The experiments used the method of repeated random splits to ensure the stability of the results. The comparisons of performance among different methods under different amounts of data can be made via repeated multiple runs.

Table 6 presents the ACC results for all eight methods. In order to better visualize the classification capabilities of each method, the AUC for classification accuracy is proposed. Figure 3 depicts the ACC curves of all eight methods with 90% of training set size.

*Table 6: The ACC values of each model*

| | 60% | 70% | 80% | 90% |
|---|---|---|---|---|
| IRT | 0.593 | 0.602 | 0.618 | 0.628 |
| MIRT | 0.642 | 0.651 | 0.661 | 0.672 |
| Neural CD | 0.738 | 0.745 | 0.758 | 0.782 |
| IKNCD | 0.746 | 0.757 | 0.770 | 0.781 |
| NACD | 0.758 | 0.774 | 0.785 | 0.795 |
| DINA | 0.584 | 0.592 | 0.607 | 0.631 |
| GDINA | 0.673 | 0.679 | 0.689 | 0.701 |
| seq-GDINA | 0.769 | 0.782 | 0.793 | 0.811 |

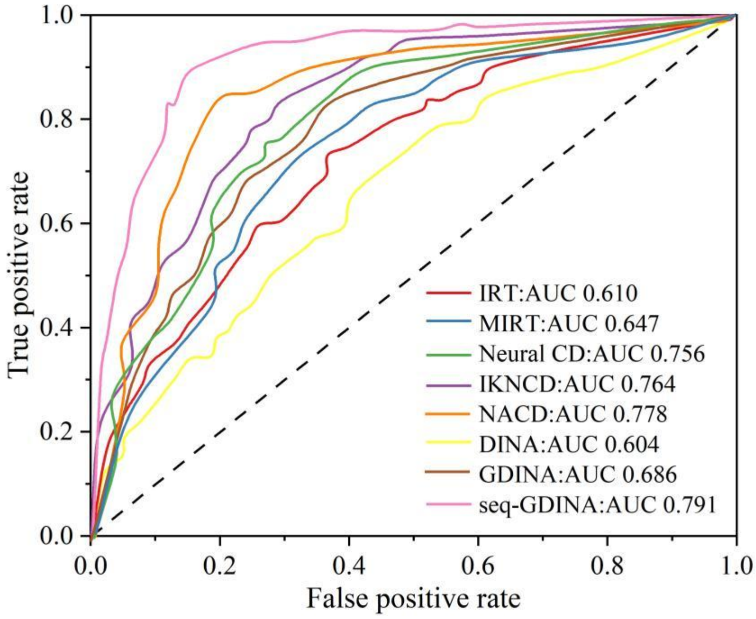


*Figure 3: The ACC curves of each model under a 90% training set ratio*

According to the values of ACC for each of the models as depicted in Table 6, at a training dataset of 90%, the seq-GDINA model provides the highest level of prediction accuracy (0.811) while performing much better than classical cognitive models including DINA (0.631) and IRT (0.628). The model is also ahead of neural network assisted models including NACD (0.795) and GDINA (0.701), providing more effective discrimination when dealing with complex sequential numerical security literacy test items. Figure 3 demonstrates that seq-GDINA model also has the greatest area under the ACC performance curve (AUC = 0.791).

The results of the RMSE and F1 scores for each of the models are displayed in Table 7 and Figure 4.

*Table 7: The RMSE values and F1 score of each model*

| | RMSE | | | | F1 | | | |
|---|---|---|---|---|---|---|---|---|
| | 60% | 70% | 80% | 90% | 60% | 70% | 80% | 90% |
| IRT | 0.498 | 0.493 | 0.485 | 0.476 | 0.469 | 0.478 | 0.491 | 0.501 |
| MIRT | 0.486 | 0.481 | 0.476 | 0.461 | 0.585 | 0.594 | 0.608 | 0.628 |
| Neural CD | 0.451 | 0.439 | 0.434 | 0.430 | 0.629 | 0.637 | 0.645 | 0.655 |
| IKNCD | 0.438 | 0.432 | 0.425 | 0.421 | 0.653 | 0.663 | 0.679 | 0.688 |
| NACD | 0.428 | 0.420 | 0.414 | 0.410 | 0.688 | 0.697 | 0.708 | 0.723 |
| DINA | 0.506 | 0.493 | 0.488 | 0.484 | 0.426 | 0.446 | 0.458 | 0.473 |
| GDINA | 0.434 | 0.421 | 0.413 | 0.408 | 0.683 | 0.701 | 0.713 | 0.725 |
| seq-GDINA | 0.405 | 0.393 | 0.387 | 0.377 | 0.778 | 0.799 | 0.810 | 0.818 |

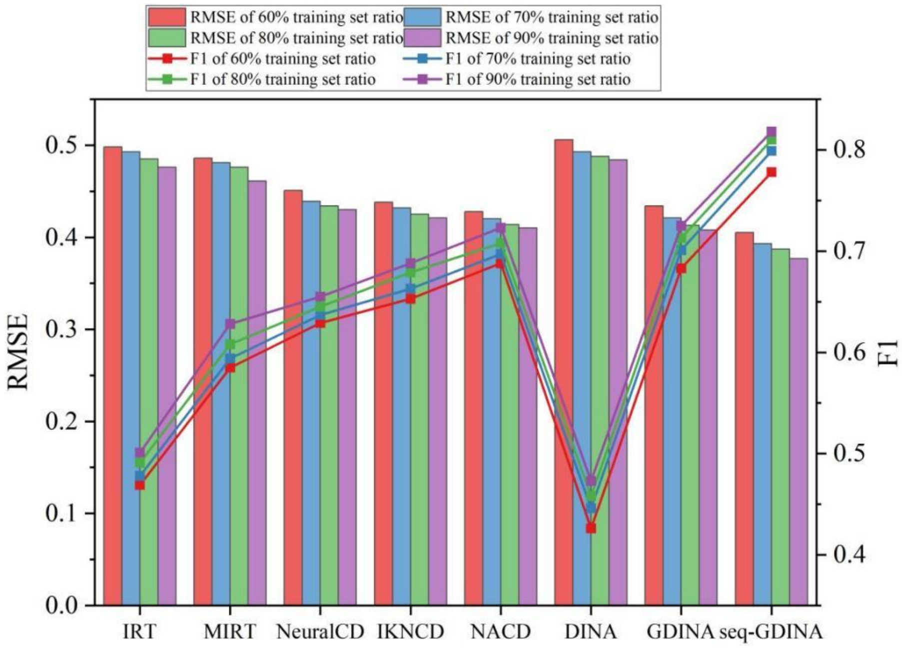


*Figure 4: The RMSE values and F1 score of each model*

With regard to RMSE, seq-GDINA showed the lowest RMSE for each proportion, obtaining an excellent result of 0.377 at 90%. It is way better compared to conventional models including DINA (0.484) and IRT (0.476), and even compared to other neural network models, for instance, NACD (0.410) and GDINA (0.408). Thus, it gives us the best error control. As for the F1 score, seq-GDINA is also superior to all the above-listed models; thus, it provides 0.818 for 90% of training sets, which is much higher compared to NACD's 0.723 and GDINA's 0.725. It shows superiority in the positive/negative sample classification and high confidence classification tasks.

### 3.3.3 Visual Analysis of Student Attributes

In order to validate the performance of seq-GDINA in modeling and analyzing the attribute capability levels for predicting the digital safety literacy of adolescents, a comparison was made between seq-GDINA and the top-performing neural network augmented models, Neural CD, IKNCD, and NACD8. The cognitive diagnosis results of students based on attributes by different models are given in Table 8, and their attribute cognitive diagnosis radar charts are depicted in Figure 5.

*Table 8: The model's cognitive diagnosis of students' various attributes*

| | Student ability score(0-10) | | | | |
|---|---|---|---|---|---|
| | IJ | SP | SC | LC | SE |
| Neural CD | 4.57 | 5.11 | 3.14 | 1.79 | 5.31 |
| IKNCD | 8.12 | 7.02 | 1.85 | 3.51 | 8.23 |
| NACD | 6.38 | 5.87 | 3.42 | 6.04 | 9.32 |
| seq-GDINA | 9.16 | 8.42 | 5.71 | 7.25 | 6.82 |
| Real | 9.26 | 8.14 | 5.32 | 7.88 | 6.99 |

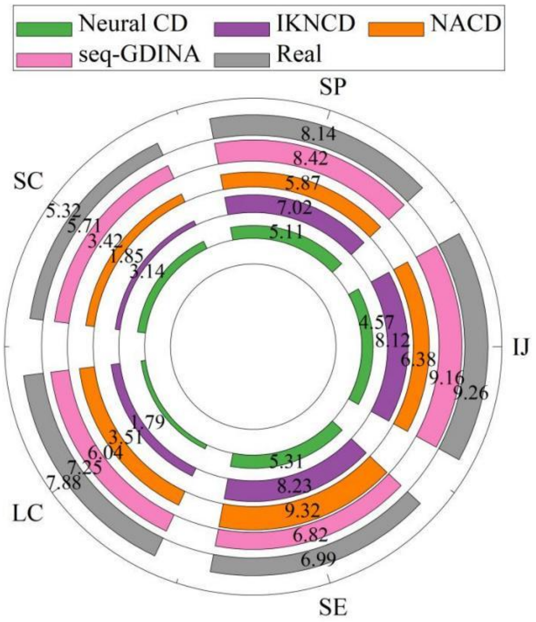


*Figure 5: Cognitive diagnostic radar charts for each attribute of students*

In this study, seq-GDINA showed higher fitting performance for all attributes by providing prediction accuracies of up to 96.67%. In comparison, the predictions made by other sophisticated models deviated from the real figures at various levels. For example, IKNCD underestimated the security collaboration attribute (predicted value: 1.85, real value: 5.32) and the legal compliance attribute; whereas, NACD overestimated the emergency resolution attribute (predicted value: 9.32, real value: 6.99). The reason why other sophisticated models showed low prediction accuracies lies in the fact that seq-GDINA is capable of taking into consideration the non-compensatory relationships between attributes in sequence. Black-box models such as Neural CD are data-driven models; therefore, prediction results can be affected by the distribution characteristics of the training sample. Some attributes like SC and LC require situational judgment and ethical cognition, and they contain many layers of abstraction and context dependencies. The traditional models or some models in neural networks cannot adequately model their mechanisms. In conclusion, the multi-stage scoring system and sequential attribute modeling ability of seq-GDINA make it perform better for most attributes compared with other models.

# 4 Building Targeted Pathways for Enhancing Digital Safety Literacy Among Youth and Analyzing Their Application Outcomes

Based on the gaps found in adolescent digital safety literacy through the empirical diagnosis conducted in Chapter 3, this chapter also develops a specific way of improving adolescents' digital safety literacy. An experiment will be designed and tested for validity, and improvement in literacy will be measured using a multi-dimensional metric system.

## 4.1 Pathways for Enhancing Digital Safety Literacy Among Youth

In light of the findings from the diagnostic test on adolescents' digital safety literacy, especially in terms of their strengths and weaknesses in the five critical areas of information recognition, self-protection, secure communication, legal awareness, and emergency response, the article offers the following suggestions for improving literacy.

#### 4.1.1 Targeted Educational Interventions

Through the cognitive test, it is clear that many students are lacking in the areas of "Legal Compliance and Digital Ethics" as well as "Security Response and Problem Solving," especially so within the moderate section. Hence, it is important that there be an emphasis on legal education, which includes topics like digital ethics and cybersecurity laws in subjects like Information Technology and Ethics as well as Rule of Law during primary and secondary school years. This can be achieved through the use of real-life examples as well as situational simulations to help improve their understanding of rules and sense of responsibility. Alongside, training classes can be conducted to focus on "Security Incident Response."

#### 4.1.2 Establishing a Collaborative Support System Integrating Home, School, and Society

It is evident that "safe communication and collaboration" is a relatively weak area for learners. Educational institutions need to cooperate with parents in developing comprehensive educational programs, which will help learners detect risks and communicate safely in a real social context using workshops organized for parents and tasks between parents and children related to digital safety. The community, industry, and social sector are expected to engage in creating digital safety education materials, like interactive simulations of phishing attacks and privacy settings, contributing to a positive societal education environment.

#### 4.1.3 Strengthen Teacher Training and School-Based Curriculum Development

Educators require additional professional development to become literate in digital safety, which will allow them to understand how to interpret cognitive diagnostic assessments. They should be capable of delivering customized instruction using the Q Matrix and pattern recognition. Schools are recommended to design a curriculum on digital safety at schools, including modules with authentic scenarios relevant to children's lives, such as social networking, gaming, and e-learning.

#### 4.1.4 Promoting Policy Support and Interdisciplinary Integration

It is suggested that education departments adopt digital security literacy as one of the core competencies and develop an interdisciplinary educational system. This involves embedding digital ethics, information discrimination skills, and psychological safeguarding into courses including language arts, politics, and psychology. At the same time, greater investment will help facilitate innovative collaboration between higher education institutions, research centers, and secondary schools regarding digital security education development models.

### 4.2 Analysis of the Application Effectiveness in Enhancing Digital Safety Literacy Among Youth

In order to verify the feasibility of the above-mentioned enhancement pathway for adolescent digital safety literacy, a semesters-long teaching trial was conducted in Grade Eight of a middle school. The cognitive diagnosis-based precision teaching model was adopted among 46 students. After completing the semesters-long education course, the effectiveness of the enhancement pathway was measured from different aspects using the Adolescent Digital Safety Literacy Evaluation System. Table 9 below illustrates students' assessment of the results of the improvement pathway on all indicators.

*Table 9: The evaluation results of students regarding the improvement effects*

| Primary indicator | Secondary indicator | Tertiary indicator | Improvement effect | | | |
|---|---|---|---|---|---|---|
| | | | Significantly improved | Improved | Generally improved | Not improved |
| Information Recognition and Judgment Ability | IJ1 | C1 | 39 | 6 | 1 | 0 |
| | | C2 | 32 | 11 | 2 | 1 |
| | IJ2 | C3 | 40 | 5 | 0 | 1 |
| | | C4 | 36 | 6 | 4 | 0 |
| Self-Protection in the Digital Environment | SP1 | C5 | 30 | 14 | 2 | 0 |
| | | C6 | 36 | 6 | 3 | 1 |
| | SP2 | C7 | 37 | 6 | 3 | 0 |
| | | C8 | 40 | 3 | 2 | 1 |
| | SP3 | C9 | 30 | 10 | 5 | 1 |
| | | C10 | 39 | 5 | 1 | 1 |
| Secure Communication and Collaboration | SC1 | C11 | 39 | 5 | 2 | 0 |
| | | C12 | 30 | 10 | 5 | 1 |
| | SC2 | C13 | 35 | 8 | 2 | 1 |
| | | C14 | 34 | 8 | 4 | 0 |
| Legal Compliance and Digital Ethics | LC1 | C15 | 38 | 6 | 1 | 1 |
| | | C16 | 41 | 4 | 0 | 1 |
| | LC2 | C17 | 36 | 8 | 2 | 0 |
| | | C18 | 32 | 12 | 1 | 1 |
| Safety Emergency and Problem Solving | SE1 | C19 | 34 | 7 | 4 | 1 |
| | | C20 | 30 | 9 | 7 | 0 |
| | SE2 | C21 | 34 | 10 | 2 | 0 |
| | | C22 | 36 | 7 | 2 | 1 |

On the whole, the effects of the interventions were quite positive on almost all indicators. Over 30 students scored “significant improvement” in all the indicators, which suggests that the paths to enhance DSSL are widely acknowledged and proved to be effective. Notably, in the areas of information identification and judgment, and self-protection in cyberspace, several sub-indicators like C1 (identification of disinformation and rumors), C3 (awareness and protection of personal sensitive information), C8 (management of personal information disclosure extent), and C10 (cyberbullying and malicious information countermeasures) were found to score “significant improvement” in the responses of over 85% of participants. Thus, it is clear that basic safety skills, closely associated with everyday living, can be significantly reinforced via the intervention. The DSSL enhancement pathways introduced in this research have shown significant success on most DSSL indicators and especially outstanding results in knowledge and behavioral normative domains. Yet, there is still some space for further optimization in more complicated applications and scenarios.

# 5 Conclusion

In this paper, we explore the improvement of digital safety literacy in teenagers during the intelligent media age. By employing the Cognitive Diagnostic Assessment approach and the seq-GDINA multi-level evaluation framework, a practical and feasible literacy assessment and educational strategy system is developed.

Through empirical analysis grounded in the accurate data gathered from 253 Grade 8 students, 16 attribute proficiency profiles were discovered. The results show that merely 13.50% of the adolescents have acquired all five essential attributes (i.e., information identification, self-protection, safe cooperation, legal compliance, and emergency handling). Thus, there exist obvious structural deficiencies in the present digital safety literacy of young people. Particularly, "Legal Compliance and Digital Ethics" and "Emergency Safety Response and Problem Solving" tend to be challenging for teenagers, with non-proficiency rates up to 26.37% and 21.86%, respectively.

With respect to model evaluation, seq-GDINA performed optimally in terms of various measures: the predictive accuracy (ACC) attained was 0.811, while the root mean squared error (RMSE) was minimal at 0.377; moreover, the F1 score was 0.818. It must be noted that these indicators clearly surpassed those provided by conventional models such as DINA and IRT as well as neural network-based models including Neural CD and NACD. Additionally, seq-GDINA made predictions closest to reality for each attribute, with an accuracy rate of 96.67%. This attests to the validity of applying seq-GDINA in high-order, multifaceted, sequential cognitive diagnostic tests.

The enhancement strategy proposed, involving "precision education," "school-home-community cooperation," "professional growth of teachers," and "policy guarantees," proved successful when implemented in pedagogical practices. In fact, more than 85% of students exhibited "significant progress" in their basic safety knowledge concerning "information discrimination," "privacy safeguards," and "cyberbullying responses."

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