Research on the classification of dimensional performance and feature extraction of primary school students' core literacy in science curriculum

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ABSTRACT

The core competency-oriented curriculum reform has become an important issue in the current education field. In order to objectively evaluate the development status of primary school students' core literacy in science courses, this study used cluster analysis method to classify students' core literacy in science and its four dimensions into three different development levels based on the interview performance of 235 students. The results of discriminant analysis show that there are significant differences between the three types of student groups, and the classification accuracy reaches 94.5%, which fully verifies the scientificity and reliability of the classification standard. On this basis, combined with the specific performance of various types of students, this study quantitatively and qualitatively described the primary school science core literacy and its four dimensions of development level, and further revealed the stage characteristics of the development of primary school science core literacy. In addition, based on the performance criteria that have been constructed, this study deeply explores the development trajectory of students' science core literacy. Through descriptive statistics, analysis of variance (ANOVA), chi-square test and multinomial logistic regression analysis, it was found that students 'performance in science core literacy and its four dimensions showed a progressive trend with the improvement of grade, and there were significant differences between different grades. Specifically, the lower grade students mainly performed at the first level, the middle grade students mainly performed at the second level, and the upper grade students mostly achieved the third level. This finding not only verified the growth law of science core literacy, but also provided empirical support for the phased training objectives of primary school science education.

Keywords: Science Curriculum; Core Competencies; Grade-Level Characteristics; Structure; Logistic Regression Analysis

1 INTRODUCTION

Core competencies have become a key concept in contemporary educational reform, emphasizing the cultivation of essential character traits and critical skills that enable students to adapt to future societal developments. At the stage of basic education, fostering core competencies in the science curriculum is crucial for enhancing students' scientific literacy, critical thinking skills, and ability to solve real-world problems. However, systematic research on elementary school students' core competencies in science courses remains relatively limited. In particular, in-depth analyses of the developmental characteristics, performance standards, and influencing factors of students at different grade levels are still lacking. Therefore, scientifically and reasonably assessing the current state of elementary school students' core competencies in science courses holds significant theoretical value and practical implications for optimizing curriculum design and improving teaching practices.

2 RELATED RESEARCH

Science education serves as the foundation for building an innovative nation and should take on the crucial responsibility of cultivating scientific and technological talent. According to a report by Eurostat, human resource statistics in the fields of science and technology are key indicators for measuring the knowledge economy and its evolution. As noted by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science (ICSU), science education is a critical factor in developing a country's or region's scientific and technological capabilities [1]. Science education is also rapidly globalizing, with many countries making new efforts to establish higher standards for students' science learning. Since the 1980s, as globalization has intensified, debates over the objectives of science education have become increasingly heated worldwide [2]. In response to the rapid advancement of science and technology and the growing prominence of social science issues, the concept of scientific literacy has gained international recognition through global collaboration.

With the increasing influence of the Programme for International Student Assessment (PISA) on global education policies, countries around the world have begun developing localized core competencies for student development as well as science curriculum core competencies [3]. Large-scale international student achievement assessments are shaping national perspectives on science education. In fact, half of the European countries explicitly reference results from international assessments such as the Trends in International Mathematics and Science Study (TIMSS) and PISA when discussing science education standards[3]. Many countries are now formulating more specific science education standards to enhance students' performance in these assessments. Clearly, the concept of science curriculum core competencies is globally shaping science education and has become a shared goal in international science education. However, each country has a unique educational history and cultural values, which influence how science curriculum core competencies are defined and how science education goals are formulated [4]. Major developed countries and regions such as the United States; the United Kingdom; Finland; Australia; Canada; South Korea; and Japan have initiated research on science education goal frameworks based on core competencies [5]. Meanwhile, countries such as South Africa and Bangladesh have also begun exploring science curriculum core competencies adapted to their local contexts, while reflecting on the relationship between their national science education standards and international benchmarks in the context of globalization [6]. At the same time, scholars have been critically reexamining the concept and connotations of core competencies. Li Yi and Zhong Baichang pointed out that the OECD (Organization for Economic Co-operation and Development) may view the depiction of intrinsic human qualities as "competencies" and describe these qualities from a functionalist perspective as "core competencies." [7]. The European Union's core competency framework, while addressing intrinsic human qualities, also exhibits a clear functional orientation toward problem-solving. However, both the OECD and the EU have merely provided surface-level interpretations of core competencies without demonstrating their conceptual validity or the completeness of their frameworks.

Gao Desheng further argued that the OECD's core competencies are not based on human dignity and well-being but on market competitiveness [8]. Its theoretical foundation lies in human capital theory, which treats individuals as human capital or as instruments for economic development. Gao agreed with Martha Nussbaum's view that education should not merely enhance individuals' competitive success but should cultivate essential human capabilities based on dignity [9]. He opposed the subjugation of life and educational principles to economic imperatives. It is evident that science curriculum core competencies represent the contemporary evolution of the scientific literacy concept, and localizing science curriculum core competencies has become an international trend in science education reform. Miller and Laugksch argued that scientific literacy is a social construct that evolves with changing contexts and times [10]; its meaning varies across different historical periods, geographic regions, communities, and societies. Similarly, Sjostrom and Eilks described scientific literacy as a boundary object—a concept upon which broad consensus can be reached, yet whose specific meaning varies among different stakeholders [11]. This underscores the difficulty and impracticality of providing an absolute definition of scientific literacy.

With the increasing influence of the Programme for International Student Assessment (PISA) on global education policies, countries around the world have begun developing localized core competencies for student development as well as science curriculum core competencies [12]. Large-scale international student achievement assessments are shaping national perspectives on science education. In fact, half of the European countries explicitly reference results from international assessments such as the Trends in International Mathematics and Science Study (TIMSS) and PISA when discussing science education standards [13]. Many countries are now formulating more specific science education standards to enhance students' performance in these assessments. Clearly, the concept of science curriculum core competencies is globally shaping science education and has become a shared goal in international science education. However, each country has a unique educational history and cultural values, which influence how science curriculum core competencies are defined and how science education goals are formulated. Major developed countries and regions such as the United States; the United Kingdom; Finland; Australia; Canada; South Korea; and Japan have initiated research on science education goal frameworks based on core competencies [14]. Meanwhile, countries such as South Africa and Bangladesh have also begun exploring science curriculum core competencies adapted to their local contexts, while reflecting on the relationship between their national science education standards and international benchmarks in the context of globalization [15].

3 RESEARCH ON PERFORMANCE STANDARDS OF PRIMARY SCHOOL STUDENTS' SCIENCE CURRICULUM CORE LITERACY

Some studies suggest that teachers often struggle to analyze student performance, provide effective learning feedback, and make timely instructional adjustments due to the lack of a referenceable series of learning performance standards. This indicates that performance standards play a crucial role in preventing the disconnect between assessment and instructional content, acting as a bridge between core competencies and assessment evaluation. Consequently, curriculum standards in various countries have begun to define and specify the core competencies students should develop at different educational stages, along with their corresponding proficiency levels. This chapter establishes performance standards for elementary school students' core competencies in science courses by coding the clinical interview performances of 235 students from both the preliminary and main studies, following a structured coding scheme. Cluster analysis and discriminant analysis were employed to classify student performance and develop these standards.

3.1 Performance Standards for Overall Science Curriculum Core Competencies

In this study, elementary school students' science curriculum core competencies are represented by four dimensions: scientific concepts, scientific inquiry, scientific thinking, and scientific attitude. The performance standards for these four dimensions have been established in previous analyses. The following section defines the overall performance standards for students' science curriculum core competencies.

3.1.1 Construction of Performance Standards

The Rasch scores for the four dimensions (scientific concepts, scientific inquiry, scientific thinking, and scientific attitude) were used in SPSS to classify students' overall science curriculum core competencies into different levels using two-step clustering and discriminant analysis, followed by an evaluation of classification validity.

Table 1: Clustering Results for Overall Science Curriculum Core Competencies

Cluster	1	2	3
Number of People	69	92	74
Proportion	29.4%	39.1%	31.5%

Cluster	1	2	3
Overall Mean Score	-15.52	-3.31	11.81
D1 (Scientific Concepts) Mean Score	-5.14	-2.21	3.45
D2 (Scientific Inquiry) Mean Score	-3.31	-0.24	2.77
D3 (Scientific Thinking) Mean Score	-3.27	-0.32	2.35
D4 (Scientific Attitude) Mean Score	-3.80	-0.53	3.24

Based on the clustering results, the three performance levels for students' science curriculum core competencies were defined as Level 1, Level 2, and Level 3. Among the 235 students: 69 students were classified as Level 1, accounting for 29.4%. 92 students were classified as Level 2, accounting for 39.1%. 74 students were classified as Level 3, accounting for 31.5%. Using the clustering analysis results, students' science curriculum core competencies were categorized into these three levels. Discriminant analysis results showed that the Rasch scores for all four dimensions significantly differentiated students' overall performance levels: $F1\ (Scientific\ Concepts) = 332.00, p < 0.001$; $F2(Scientific\ Inquiry) = 399.18, p < 0.001$; $F3(Scientific\ Thinking) = 352.13, p < 0.001$; $F4(Scientific\ Attitude) = 273.58, p < 0.001$; The discriminant function: $Y = 0.51 + 0.241D_1 + 0.33D_2 + 0.20D_3 + 0.22D_4$. Achieved an explanatory power of 98.5%, reaching a significant level. To determine students' science curriculum core competency levels, the Fisher linear discriminant function was used. Students' Rasch scores in each of the four dimensions were substituted into the functions below, and the level with the highest computed value was assigned to the student. The three Fisher linear discriminant functions were:

$$\begin{aligned} F_{\text{Level1}} &= -8.45 - 0.95D_1 - 1.15D_2 - 0.88D_3 - 0.75D_4 \\ F_{\text{Level2}} &= -1.56 - 0.54D_1 - 0.01D_2 + 0.08D_3 - 0.15D_4 \\ F_{\text{Level3}} &= -5.41 + 0.61D_1 + 1.08D_2 + 0.51D_3 + 0.68D_4 \end{aligned} \tag{1}$$

The three clustering-based levels correctly classified 95.3% of students in the initial group and 94.5% in the cross-validation group, confirming that the three-level classification of science curriculum core competencies is valid.

3.1.2 Characteristics of Performance Standards

The performance characteristics of elementary school students' science curriculum core competencies were evaluated both quantitatively and qualitatively across the four dimensions: Scientific Concepts; Scientific Inquiry; Scientific Thinking; Scientific Attitude.

Table 2: Proportions of Different Levels in the Science Curriculum Core Competency Dimensions

Level	Indicator	Proportion
Level 1 (69/29.4%)	Scientific Concepts	Level 1 (65/94.2%); Level 2 (4/5.8%)
	Scientific Inquiry	Level 1 (62/89.9%); Level 2 (7/10.1%)
	Scientific Thinking	Level 1 (63/91.3%); Level 2 (6/8.7%)
	Scientific Attitude	Level 1 (64/92.8%); Level 2 (5/7.2%)
Level 2 (92/39.1%)	Scientific Concepts	Level 1 (28/30.4%); Level 2 (61/66.3%); Level 3 (3/3.3%)
	Scientific Inquiry	Level 1 (8/8.7%); Level 2 (69/75.0%); Level 3 (15/16.3%)
	Scientific Thinking	Level 1 (16/17.4%); Level 2 (57/70.0%); Level 3 (19/20.6%)
	Scientific Attitude	Level 1 (31/33.7%); Level 2 (43/46.7%); Level 3 (18/19.6%)
Level 3 (74/31.5%)	Scientific Concepts	Level 2 (17/23.0%); Level 3 (57/77.0%)
	Scientific Inquiry	Level 2 (8/10.8%); Level 3 (66/89.2%)
	Scientific Thinking	Level 2 (8/10.8%); Level 3 (66/89.2%)
	Scientific Attitude	Level 2 (11/14.9%); Level 3 (63/85.1%)

3.2 Summary

By transforming the original scores of each dimension into Rasch scores, the objective evaluation can be carried out. According to the evaluation standard of 13 indicators tested, cluster analysis and discriminant analysis are carried out on the four dimensions and the overall performance, and the sample student performance is divided into three different levels, and the group characteristics of each level are qualitatively described.

The four dimensions and the three levels of overall core literacy performance share the following common features:

(1) The comprehensive ability of students from level 1 to level 3 has been continuously improved. Although the level of each dimension and the performance of the overall science curriculum core literacy did not correspond to the index level, the overall ability was constantly improved. For example, in the performance of the core literacy of the overall science curriculum, the students of level 1 were mainly composed of level 1 and level 2 of the four dimensions, and level 1 accounted for the majority. Overall science curriculum core literacy level 3 students are mainly composed of a combination of performance at levels 2 and 3 in the four dimensions, with level 2 being a minority. From low to high levels, the performance of each dimension and the overall science curriculum core literacy increased.

(2) The performance of the four dimensions and the overall core literacy is unbalanced. The high level group does not necessarily show high level in each dimension and each observation index. Conversely, low-level groups do not necessarily behave as low-level in all dimensions and observation indicators. For example, level 3 of the scientific attitude dimension is not only corresponding to level 3 of the three indicators of inquiry interest, seeking truth from facts and cooperation and sharing, but is composed of level 1, level 2 and level 3 of the three indicators. Students with level 3 of overall literacy do not all perform at level 3 in all four dimensions. Students with level 3 of overall core literacy may also perform at the combination of level 2 and level 3 in the four dimensions.

4 THE LEARNING PHASE CHARACTERISTICS OF PRIMARY SCHOOL STUDENTS' SCIENCE CURRICULUM CORE LITERACY

The sample of primary school students collected in this study was between 6 and 13 years old. among the four dimensions of primary school students' science curriculum core literacy, the dimension of scientific concept has the largest range. The highest mean value is for the dimension of scientific inquiry, and the lowest value is for the dimension of scientific concept.

Table 3: Descriptive Statistics of the Four Dimensions (Rasch Scores)

Dimension	Sample Size (N)	Mean	Standard Error	Standard Deviation	Min	Max	Range
Scientific Concepts	235	-1.29	0.26	3.99	-5.92	5.49	11.40
Scientific Inquiry	235	-0.20	0.18	2.70	-4.60	4.59	9.18
Scientific Thinking	235	-0.35	0.17	2.53	-4.44	4.24	8.68
Scientific Attitude	235	-0.30	0.21	3.29	-4.88	4.69	9.57

4.1 Overall Science Curriculum Core Competency Performance

4.1.1 Descriptive Statistics

Elementary school students' science curriculum core competencies were classified into three levels.

Table 4: Distribution of Science Curriculum Core Competency Levels Across Grade Groups

Grade Group	Level 1		Level 2		Level 3	
	N	%	N	%	N	%
Lower Grades (Grades 1-2)	43	55.1%	22	28.2%	13	16.7%
Middle Grades (Grades 3-4)	19	24.4%	35	44.9%	24	30.8%
Upper Grades (Grades 5-6)	7	8.9%	35	44.3%	37	46.8%

From the overall performance of students' science curriculum core competencies, it is evident that students' competency levels increase as grade level progresses. The proportion of Level 1 students decreases as grade level increases. The proportion of Level 3 students increases as grade level increases. In lower grades, most students are at Level 1. In middle grades, most students are at Level 2. In upper grades, most students are at Level 3.

4.1.2 Differences in Students' Overall Science Curriculum Core Competency Levels

Since students' overall science curriculum core competencies were categorized into three levels, ANOVA (Analysis of Variance) cannot be used for statistical comparisons. Instead, Chi-square tests were conducted to analyze the interaction effects between five background variables (urban/rural location, grade level, gender, academic performance, and task type) and science curriculum core competency levels.

Table 5: Chi-Square Test Results for Different Variables

Variable	Level 1	Level 2	Level 3	χ^2	p
Urban	18 (15.7%)	40 (34.8%)	57 (49.6%)	38.88	<0.001
Rural	51 (42.5%)	52 (43.3%)	17 (14.2%)		
Lower Grades	43 (55.1%)	22 (28.2%)	13 (16.7%)	44.55	<0.001
Middle Grades	19 (24.4%)	35 (44.9%)	24 (30.8%)		
Upper Grades	7 (8.9%)	35 (44.3%)	37 (46.8%)		
Male	30 (22.7%)	49 (37.1%)	53 (40.2%)	12.01	0.002
Female	39 (37.9%)	43 (41.7%)	21 (20.4%)		
Low Academic Performance	28 (51.9%)	20 (37.0%)	6 (11.1%)	22.33	<0.001
Medium Academic Performance	13 (24.1%)	24 (44.4%)	17 (31.5%)		
High Academic Performance	28 (22.2%)	48 (38.1%)	50 (39.7%)		
Task: Seed Growth	12 (22.2%)	27 (50.0%)	15 (27.8%)	8.38	0.212
Task: Heat Transfer	18 (25.0%)	29 (40.3%)	25 (34.7%)		
Task: Moon Phases	21 (38.9%)	14 (25.9%)	19 (35.2%)		
Task: Bridges	18 (32.7%)	22 (40.0%)	15 (27.3%)		

From the 235 student samples, the majority of elementary school students were classified at Level 2 for their science curriculum core competencies. The data revealed the following trends: Urban students were more likely to be classified as Level 3, while rural students were less likely to reach this level. Lower-grade students had fewer students at Level 3, whereas higher-grade students had fewer students at Level 1. Male students were more likely to be classified as Level 3, while female students were less represented at Level 3. Students with higher academic performance were more likely to be classified at Level 3, whereas students with lower academic performance were more frequently classified at Level 1. To further verify the impact of the four independent variables on students' science curriculum core competency levels, a multinomial logistic regression model was introduced. The sample size met the requirement of being 10 – 15 times the number of independent variables, and no multicollinearity issues or significant interaction effects were detected among the independent variables.

The dependent variable (student science curriculum core competency level) was coded as follows: $Level1 = 1$, $Level2 = 2, Level3 = 3$ (reference category). The multinomial logistic regression model is expressed as:

$$\log\left(\frac{p(\, y = j \mid x\,)}{p(\, y = J \mid x\,)}\right) = \alpha_j + \sum_{k=1}^{K} \beta_{jk} x_k \quad (2)$$

Where $j = 1,2,3$ represents the science curriculum core competency levels. $p(y = j)$ represents the probability of a student being classified as Level j. x_k represents the k-th independent variable affecting students' core competency levels. β_{jk} represents the regression coefficients for the independent variables. The odds ratio (OR value) represents the likelihood of a student being at a particular competency level compared to Level 3. To test these effects, the following two logistic models were established:

Model 1 (Low Level - Reference: Level 3)

$$log\left(\frac{p_1}{p_3}\right) = \alpha_1 + \sum_{k=1}^{K} \beta_{1k} x_k \quad (3)$$

Model 2 (Medium Level - Reference: Level 3)

$$log\left(\frac{p_2}{p_3}\right) = \alpha_2 + \sum_{k=1}^{K} \beta_{2k} x_k \quad (4)$$

According to the logistic regression analysis requirements, the goodness-of-fit of the model was tested.

Table 6: Model Fit Information

Model	Model Fit Condition	Likelihood Ratio Test
	-2 Log Likelihood	χ^2
Intercept Only	288.90	-
Final Model	148.76	140.14

The $p - value(< 0.05)$ indicates that the model is valid and well-fitted. To determine whether all independent variables have a significant effect, a likelihood ratio test was performed. The results show that grade level, academic performance, and urban-rural location are significant factors ($p < 0.05$), while gender is not significant ($p = 0.243$).

Table 7: Likelihood Ratio Test for Independent Variables

Variable	Model Fit Criterion	Likelihood Ratio Test
	-2 Log Likelihood	χ^2
Intercept	148.76	0.00
Grade Level	210.07	61.31
Academic Performance	193.17	44.42
Urban/Rural	204.01	55.25
Gender	151.59	2.83

Multinomial Logistic Regression Results (Model 1: Level 1 vs. Level 3)

The results of Model 1 indicate significant differences between Level 1 and Level 3 in terms of grade level, academic performance, and urban/rural location.

Table 8: Multinomial Logistic Regression (Model 1: Reference Level 3)

Level 1 (Compared to Level 3)	B	Wald	df	p	OR Value	95% CI
Intercept	-1.33	4.89	1	0.027	-	-
Lower Grades (Reference: Upper Grades)	4.32	38.22	1	<0.001	74.970	(19.08, 294.64)
Middle Grades (Reference: Upper Grades)	2.07	10.78	1	0.001	7.912	(2.30, 27.20)
Low Academic Performance (Reference: High Performance)	3.96	31.88	1	<0.001	52.280	(13.24, 206.44)
Medium Academic Performance (Reference: High Performance)	1.15	3.89	1	0.049	3.167	(1.01, 9.96)
Urban (Reference: Rural)	-3.56	40.77	1	<0.001	0.028	(0.01, 0.09)

The regression analysis results of Model 2 showed that there were differences between the three factors of school stage, usual performance, and urban and rural areas on the performance of students 'core literacy of science curriculum at level 2 or level 3. The specific differences are as follows:

Learning segment factor: Low segment students are 6.98 times more likely to perform at level 2 but not at level 3 than high segment students. That is, students in lower segments are more likely to perform at level 2 and students in higher segments are more likely to perform at level 3. There was no significant difference in the performance of level 2 and level 3 between middle and high level students.

Performance factor: Students with low usual scores are 13.05 times more likely to perform at level 2 but not at level 3 than students with high usual scores. That is, students with low usual scores are more likely to perform at level 2 in terms of core literacy in science courses, and students with good usual scores are more likely to perform at level 3. The probability of performing at level 2 is higher for students with medium usual scores compared to students with high usual scores.

Urban and rural factors: Urban students are less likely to perform at level 2 and not at level 3 than rural students. That is, rural students are more likely to perform at level 2 and urban students are more likely to perform at level 3.

4.2 Summary of this chapter

Statistics of the level of students in each stage in the four dimensions of scientific concept, scientific inquiry, scientific thinking and scientific attitude, it was found that from the low stage to the high stage, the performance level of students in the four dimensions gradually improved, the proportion of low level performance gradually decreased, and the number of students with middle and high level performance gradually increased. The Rasch scores of the four dimensions were analyzed by one-way analysis of variance, and the results showed that there were significant differences in the performance of the four dimensions between the learning segments. The performance of scientific concept, scientific inquiry, scientific thinking and scientific attitude of the students in the low group were significantly lower than those in the middle and high groups. The performance of students in the middle segment was also significantly lower than that in the high segment in terms of four dimensions.

In terms of the core literacy performance of the overall science curriculum, the majority of students in each stage were at level 2. Chi-square test showed that four factors, including academic stage, urban and rural area, achievement and gender, had an impact on students 'core literacy performance in science curriculum. In order to further verify the specific influence of the four independent variables on students' core literacy level of science courses, the multi-classification logistic regression model was introduced. Through the model goodness of fit test and likelihood ratio test, the regression model was effective and fitted well. The regression analysis showed that the difference in the gender factor was not significant. Factors such as school stage, usual performance and urban and rural areas have significant effects. Low level students are more likely to perform at levels 1 and 2, middle and high level students are more likely to perform at level 1, and high level students are more likely to perform at level 3. Students with low usual scores are more likely to perform at levels 1 and 2, and students with good usual scores are more likely to perform at level 3 in terms of core literacy in the science curriculum. Urban students are more likely to perform at level 3, and rural students are more likely to perform at levels 1 and 2. This also shows that the standard of performance is reasonable.

5 CONCLUSION

This study constructs the structure of primary school students' science curriculum core literacy. The core literacy of primary school students' science curriculum includes four potential dimensions of scientific concept, scientific inquiry, scientific thinking and scientific attitude. The four dimensions are composed of 13 directly observable indicators: scientific concept includes concept understanding and concept application; Scientific inquiry includes asking questions, obtaining evidence, explaining, expressing and communicating. Scientific thinking includes model construction, scientific reasoning, scientific demonstration and innovative thinking. Scientific attitude includes interest in inquiry, seeking truth from facts, cooperation and sharing, etc.

When the student performance of 13 indicators is clustered into different levels of four potential dimensions, the level feature of scientific concept is the description of understanding and application. The description of the dimension of scientific inquiry runs through all the elements of inquiry; The horizontal feature description of scientific thinking dimension also merges scientific reasoning and scientific demonstration into the same development variable.

The assessment tool for primary school students' science curriculum core literacy consisted of 13 observation indicators, and the 13 observation indicators reflected four potential dimensions. The 4-D structure fits the observed data better than the single-D structure and the 2-D and 3-D structures. The performance of the 13 observed indicators is classified into three levels, and the multi-faceted Rasch model test results show that the three levels of the 13 indicators are reasonably divided. The interview outline and coding scheme can obtain the performance data of students' science curriculum core literacy, and fit the Rasch model well, indicating that the assessment tool in this study has good construct validity and measurement reliability, and the quality of the tool is good.

ACKNOWLEDGEMENTS

Thanks for the data support provided by National-level Innovation Program Project Fund "Research on Seedling Inspection Robot Technology Based on Multi-source Information Fusion and Deep Network" (No.: 202410451009); Jiangsu Provincial Natural Science Research General Project (No.: 20KJB530008); China Society for Smart Engineering "Research on Intelligent Internet of Things Devices and Control Program Algorithms Based on Multi-source Data Analysis" (No.: ZHGC104432); China Engineering Management Association "Comprehensive Application Research on Intelligent Robots and Intelligent Equipment Based on Big Data and Deep Learning" (No.: GMZY2174); Key Project of National Science and Information Technology Department Research Center National Science and Technology Development Research Plan (No.: KXJS71057); Key Project of National Science and Technology Support Program of Ministry of Agriculture (No.: NYF251050)

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