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Higher-order thinking skills-based science literacy questions for high school students

Lesy Luzyawati[1], Idah Hamidah[1], Aditya Fauzan[1], Husamah[2]
[1]Department of Biology Education, Faculty of Teacher Training and Education, Universitas Wiralodra, Indramayu, Indonesia
[2]Department of Biology Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Malang, Malang, Indonesia

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ABSTRACT

Students' science literacy abilities must receive special attention, particularly by investigating root causes and implementing strategies for improvement. Measuring science literacy through questions is crucial to determine students' proficiency to be science literate. This research aims to produce higher-order thinking skill (HOTS)-based science literacy questions that are feasible (valid and reliable) to measure high school students' science literacy on respiratory system material. This research employed research and development (R&D) approach. This study involved 300 senior high school students across Indonesia. Research data was analyzed using confirmatory factor analysis (CFA). The empirical study revealed 20 HOTS-based science literacy questions on respiratory system material with acceptable reliability values. These results show the feasibility of the developed questions and highlight the possibility for further extensive trial stage to assess students' science literacy.

Corresponding Author:

Lesy Luzyawati
Department of Biology Education, Faculty of Teacher Training and Education, Universitas Wiralodra
Ir. H. Juanda Street, Km. 03, Indramayu, West Java 45213, Indonesia
Email: lesy.luzyawati@unwir.ac.id

1. INTRODUCTION

Science literacy is a fundamental ability essential for student to solve real-world problems related to scientific principles [1], [2]. Science literacy encompasses not only scientific concepts but also processes that enable a person to make informed decisions, involve in state systems, contribute to cultural and economic growth, as well as to utilize the specific abilities [3], [4]. Science literacy is multidimensional, meaning it is not mere knowledge acquisition, but enable individuals to apply scientific concepts and skills in daily decisions-making and interact effectively with the environment [5], [6], and comprehend the intricate interplay between science, technology and society, including the development of social and economic aspects [7].

Science literacy comprises three dimensions, namely content (science knowledge), implementation/process (science competency), and context (science application) [8]. The content aspect of science refers to the key concepts from science that are necessary to understand natural phenomena and changes in nature through human activities. The science process involves the mental processes employed in answering scientific questions and problem-solving. Lasltly, the science context aspect pertains to situations in life that provide a platform for the application of processes and understanding of science concepts [9], [10]. Additionally, Organization for Economic Co-operation and Development (OECD) in the programme for international student assessment (PISA) study formulated the scope of science literacy competencies which consist of: i) explaining phenomena scientifically, ii) evaluating and designing scientific investigations, and iii) interpreting data and evidence scientifically [11].

Science literacy is one of the keys to success in facing the challenges in the 21st century [12], where the rapid development of science requires humans to adapt to all aspects of life. Rapid developments in educational and economic aspects are strongly attributed to technological innovations and globalization [13]. The economic development of a country becomes dependent on advances in science and technology, thus requiring the creation of a science literate society [3]. In today's multicultural world, number of opportunities for learning emerge [14]. The 21st-cetury technological advancement and globalization have profoundly influenced the treatment of science, as it has become more valuable as a process in explaining the relationships and connections between humans, nature and technology [15]. Many countries worldwide are trying to make science literacy the main goal of education [16]. This is because when a science literacy attitude is developed, the development of problem-solving skills and academic success will follow [17]. In Indonesia, science literacy began to be developed in the 2006 curriculum and is more clearly visible in the 2013 curriculum through inquiry-based activities and student-centred approaches [18]. This also applies to the independent curriculum, realized through project-based learning and problem-based learning [19].

Based on data released by PISA 2018, the science literacy abilities of Indonesian students remain alarmingly low and have relatively not experienced significant changes compared to data in the previous years. Indonesian students' science literacy score of 396 is ranked 71st out of 79 participating countries and is still far below the international standard score of 438 [11]. The 2022 PISA results show that Indonesian students' literacy and science skills are still relatively low despite an increase in ranking. The literacy ability ranking of Indonesian students in 2022 is projected to be 71, while the science literacy ranking is estimated to be 67, with 81 countries included in the PISA ranking [20]. The low science literacy achievements of Indonesian students are caused by several factors, such as students not being adequately trained to solve questions at the same level as PISA questions [21], [22]. Additonally, students' inability to work on PISA test questions at levels five and six, which have a high level of difficulty, and their lack of training to apply their knowledge in solving contextual questions or problems [21], [22] is regarded the contributing issue. Students who are not used to expressing their ideas are also found unable to answer questions that relate the material to the surrounding environment [10]. Generally, students are accustomed to memorizing formulas without knowing the use of these formulas or concepts in everyday life [23].

Higher-order thinking skill (HOTS) also influences science literacy abilities. Students' science literacy are closely related to HOTS [24], [25]. Students who have high intellectual intelligence can understand theory and practice, to be able to solve the problems they face [26], [27]. When science literacy is applied, it fosters students' critical thinking and higher-level of reasoning ability [28], [29]. This is because science literacy and HOTS have a very strong correlation [30]. Science literacy can also be improved by providing several HOTS questions during learning [31], [32]. In conclusion, students with oustanding intelligence and ability in HOTS are expected to manifest strong science literacy.

HOTS is a thinking process that requires students to manipulate existing information and ideas in certain ways that give them new understanding and implications [33]. Students' thinking abilities at a higher level, especially those related to the skills to think critically in receiving various types of information, think creatively in solving problems using the knowledge they have and making decisions in complex situations [34], [35]. An example of an activity that uses HOTS is when students combine facts and ideas in the process of synthesizing, generalizing, explaining, hypothesizing and analyzing, until students arrive at a conclusion.

HOTS has several characteristics, including: i) non-algorithmic, meaning that action steps cannot be fully determined in advance; ii) complex, implying that the steps cannot be seen or predicted directly from a certain point of view; iii) generation of many solutions; iv) involvement differences of opinion or interpretation; v) the application of multiple criteria; vi) uncertainty; vii) demanding independence in the thought process; viii) impressive meaning; and ix) requiring hard work (full effort) [36]. Additionally, the fundamental characteristics of HOTS include critical thinking and creative thinking. To generate ideas in a plan requires creative thinking, but planning the idea itself requires critical thinking [37].

HOTS plays an important role in the realm of education as it influences students' speed and effectiveness in learning [25], [38]–[40], and sustainability response [41]–[45]. HOTS requires students to solve problems critically and creatively as well as decision-making to achieve learning goals [33], [46]. Students can also differentiate ideas clearly, present arguments effectively, solve problems, construct explanations, hypothesize and understand complex things clearly, where these abilities interpret students' reasoning skill [9], [47]. One important aspect of providing HOTS is its ability to create competent and competitive graduates.

Students' science literacy must receive special attention, namely by looking for causes and efforts to improve them [48]. The importance of measuring science literacy is to find out the extent ofstudents' literacy [49]. Assessing students' science literacy also aims to increase their intellectual capacity so that they have adequate thinking skills to carry out their roles [50]. Therefore, an instrument is needed that can be used to measure this ability. The development of science literacy instruments has been carried out by Zahro [51], Chasanah *et al.* [52], and Karista [53]. However, the development of science literacy instruments combined with HOTS capabilities is still rare. Indeed, a positive relationship exists between level of intelligence and science literacy [54]. Intelligence will direct a person to act purposefully, think rationally, and deal with their environment effectively [55]. Therefore, a science literacy test instrument can be developed by combining HOTS-based question types at the level of analyzing (C4), evaluating (C5) and creating (C6) [56].

HOTS-based science literacy questions can be applied to respiratory system material. This material is one of the biological materials that is difficult to understand because it contains many concepts [57], as well as the many interrelations between the concepts, functions and working mechanisms of the respiratory organs [58]. Apart from that, most of the practice questions on the respiratory system material in textbooks are at level C1-C3, making it difficult for students to answer questions at level C4-C6 [59]. Respiratory system material meets the basic principles of content selection in PISA, because it is based on the OECD [11]. The questions tested in PISA are applicable questions that not only require understanding of concepts but also critical and creative thinking skills in solving questions. Based on this, the aim of this research is to produce a HOTS-based literacy question instrument that is feasible (valid and reliable) to measure students' science literacy on respiratory system material.

This research has theoretical and practical contributions. Theoretically, it provides a basis for thinking about the urgency of developing and using HOTS-based science literacy question in educational institutions. Practically, this research produces a HOTS-based science literacy question on respiratory system material that is taught to high school students and has content links to PISA standards, so that it can later be used widely.

2. METHOD

This research employed research and development (R&D) approach. The subjects were selected using proportional random sampling, namely a proportion taking technique to obtain a representative sample, taking subjects from each stratum or region determined in a balanced or comparable manner [60]. The subjects involved 300 senior high school students across Indonesia. The validity test of the question items was analyzed using confirmatory factor analysis (CFA) with the help of SPSS 21 software. This pattern has also been carried out by several previous researchers [61], [62]. Before carrying out a validity test using CFA, it is necessary to understand the terms variables and indicators. The variables in the validity test are seven combinations of science literacy indicators with HOTS indicators, while the indicators in the validity test are 23 questions contained in the HOTS-based literacy question instrument that is being developed. The variables and indicators in the validity test can be seen in Table 1. There are three steps or conditions that must be carried out to test the validity of question items using CFA [63], [64], namely: i) Kaiser Mayer Oikin measure of sampling adequacy (KMO MSA) test analysis, ii) anti-image matrices test analysis, and iii) rotated component matrix test. The reliability test was analyzed using SPSS 21 software. The basis for decision making in the reliability test refers to the theory put forward [65], as stated in Table 2.

Table 1. CFA test variables and indicators

Variable	Indicator	Question number	Variable	Indicator	Question number
LS. 1-C4	LS. 1-C4 1	2	LS. 2-C5	LS. 2-C5 1	8
	LS. 1-C4 2	3		LS. 2-C5 2	9
	LS. 1-C4 3	6		LS. 2-C5 3	16
	LS. 1-C4 4	7		LS. 2-C5 4	17
	LS. 1-C4 5	10		LS. 2-C5 5	23
	LS. 1-C4 6	11	LS. 2-C6	LS. 2-C6 1	19
	LS. 1-C4 7	12		LS. 2-C6 2	22
	LS. 1-C4 8	14	LS. 3-C4	LS. 3-C4 1	1
LS. 1-C5	LS. 1-C5 1	4		LS. 3-C4 2	13
	LS. 1-C5 2	5		LS. 3-C4 3	15
LS. 2-C4	LS. 2-C4	18		LS. 3-C4 4	21
			LS. 3-C5	LS. 3-C5	20

Table 2. Reliability test criteria

Cronbach's Alpha value	Category
$x = 0$	No reliability
$x > 0.70$	Acceptable reliability
$x > 0.80$	Good reliability
$x > 0.90$	Excellent reliability
$x = 1$	Perfect reliability

3. RESULTS AND DISCUSSION

Validation of question items was carried out using CFA with three steps or requirements, namely the KMO MSA test, the anti-image matrices test, and the rotated component matrix test. KMO is a test carried out to determine the appropriateness of a factor analysis to be carried out. Meanwhile, the MSA test was carried out to measure the sampling adequacy of each variable. The results of the KMO MSA test analysis can be seen in Table 3.

Table 3. KMO MSA test output

KMO MSA	Bartlett's test of sphericity		
	Approx. chi-square	df	Sig.
.705	1594.358	253	.000

Based on the results of the KMO MSA test analysis in Table 3, it shows a value of 0.705 > 0.50, which means that sampling for each variable can be declared feasible, so that factor analysis can proceed to the next stage. This conclusion is based on the KMO MSA test criteria proposed by Guo [48], that if the calculated KMO MSA value is lower than 0.50, then the variable cannot be predicted and factor analysis is not feasible. Meanwhile, if the calculated KMO MSA value is greater than 0.50, then the variable can be predicted and factor analysis is feasible.

The next step is the analysis of anti-image matrices. The anti-image matrices test was carried out to find out and determine which variables are suitable for use in factor analysis. The results of the anti-image matrices test analysis can be seen in Table 4.

Table 4. Recapitulation of anti-image matrices test results

Indicator	Anti-image correlation value	Indicator	Anti-image correlation value
LS.1-C4 1	0.691	LS.2-C5 2	0.699
LS.1-C4 2	0.686	LS.2-C5 3	0.825
LS.1-C4 3	0.732	LS.2-C5 4	0.511
LS.1-C4 4	0.769	LS.2-C5 5	0.679
LS.1-C4 5	0.727	LS.2-C6 1	0.668
LS.1-C4 6	0.773	LS.2-C6 2	0.676
LS.1-C4 7	0.683	LS.3-C4 1	0.792
LS.1-C4 8	0.756	LS.3-C4 2	0.597
LS.1-C5 1	0.752	LS.3-C4 3	0.653
LS.1-C5 2	0.583	LS.3-C4 4	0.732
LS.2-C4	0.627	LS.3-C5	0.615
LS.2-C5 1	0.710		

The analysis results of the anti-image matrices test in Table 4 show that the MSA value for each indicator is greater than 0.50. As the theory put forward, that the requirements that must be met in the anti-image matrices test are the MSA value for anti-image correlation > 0.50 [66]–[69]. If the MSA value for anti-image correlation is lower than 0.50, then the variable is not suitable for use in factor analysis. Based on this explanation, it can be concluded that the variables and indicators tested have entered the MSA criteria and can be analyzed further without eliminating the indicators (question items) used.

The next step is the rotated component matrix test analysis. The rotated component matrix test is used to ensure which variables are appropriate and included in each factor. The results of the rotated component matrix test analysis can be seen in Table 5. Based on the results of the rotated component matrix test analysis in Table 5, it shows that there are three indicators or questions that are invalid or not suitable for measuring students' science literacy, namely indicators LS.1-C4 8 (question number 14), LS.2-C5 3 (question number 16), and LS.3-C4 2 (question number 13). Meanwhile, 20 other questions were declared valid or suitable for measuring students' science literacy. Questions number 14 and 16 were declared invalid because the factor loading value on the indicator was not in the correct variable column, but did not group with the variable. Meanwhile, question number 13 was declared invalid due to its factor loading value of -0.655, which was below the factor loading reference value of 0.35. This is in accordance with the theory suggested by other reserachers that if the factor loading value < the factor loading reference value (0.35) or does not group into one factor, it can be concluded that the indicators used in the variable are inconsistent or the indicators are not suitable for use [70], [71].

Data from the 20 questions that have been carried out in the CFA test must then be tested for reliability before they can be declared suitable for use to measure students' science literacy. Reliability testing was carried out to measure the consistency or reliability of the questions prepared in the HOTS-based literacy question instrument that was developed. This is in accordance with what other reseracher said that the instrument reliability test is carried out to determine whether the data produced is reliable or robust [72]. The results of the reliability test can be seen in Table 6.

Table 5. Rotated component matrix test output

Indicator	Component						
	1	2	3	4	5	6	7
LS.1-C4 1	.582						
LS.1-C4 2	.554						
LS.1-C4 3	.589						
LS.1-C4 4	.547						
LS.1-C4 5	.660						
LS.1-C4 6	.730						
LS.1-C4 7	.780						
LS.1-C4 8			.547				
LS.1-C5 1		.790					
LS.1-C5 2		.805					
LS.2-C4			.788				
LS.2-C5 1				.583			
LS.2-C5 2				.581			
LS.2-C5 3			.730				
LS.2-C5 4				.692			
LS.2-C5 5				.582			
LS.2-C6 1					.644		
LS.2-C6 2					.737		
LS.3-C4 1						.582	
LS.3-C4 2						-.655	
LS.3-C4 3						.574	
LS.3-C4 4						.514	
LS.3-C5							.731

Table 6. Reliability test output

Cronbach’s alpha	N of items
.773	20

Based on the results of the reliability test in Table 6, it shows the Cronbach's alpha value (0.773) > 0.70. This means that the reliability of the 20 questions in the HOTS-based science literacy question instrument developed is acceptable (acceptable reliability), so it is suitable or ready to be used for the trial stage to measure students' science literacy. As the theory put forward, that is, if the Cronbach's alpha value is > 0.70, it can be concluded that the reliability of the instrument is acceptable (acceptable reliability) [73].

The preparation of assessment instruments refers to validation and reliability [73], [74], so that validity and reliability are very important in preparing assessment instruments. Validity explains how well the data collected in a study is, as well as assessing whether the instruments used in the research can measure what is intended to be measured [75]. Meanwhile, reliability explains the extent to which measurement of a phenomenon can provide stable and consistent results [76]. A measurement can be said to be reliable if the measurement activity is carried out repeatedly under constant conditions and produces the same results [77]. This is in line with the opinion that an assessment instrument can be said to have high validity and reliability if the assessment instrument carries out its measuring function or provides precise and accurate measuring results in accordance with the purpose of the test [78].

4. CONCLUSION

Based on the results of the development, it can be concluded that i) The HOTS-based literacy questions on respiratory system material are feasible and ready to be used to measure the science literacy of senior high school students and ii) A HOTS-based science literacy question has been produced on respiratory system material, consisting of 20 questions with acceptable reliability values. The implementation of HOTS-based science literacy question instruments on respiratory system material can be carried out by teachers or researchers widely in Indonesia so that they can determine the level of science literacy abilities of senior high school students.

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BIOGRAPHIES OF AUTHORS

Lesy Luzyawati is an assistant professor at Department of Biology Education, Faculty of Teacher Training and Education, Universitas Wiralodra. She graduated with a bachelor's degree in Biology Education, Universitas Pendidikan Indonesia in 2009, a Masters in Biology Education at the Postgraduate Program Universitas Kuningan at 2015. Since 2018 until now, the author has been active as Editor in chief of the Mangifera Edu journal. The author has also been involved in several biology lesson study activities and various research activities that focus on the fields of biology education, HOTS, scientific reasoning, science literacy, and biodiversity conservation. She can be contacted at email: lesy.luzyawati@unwir.ac.id.

Idah Hamidah is an asisstant professor at Department of Biology Education, Faculty of Teacher Training and Education, Universitas Wiralodra. She graduated with a bachelor's degree in Biology Education at Wiralodra University in 2012, a Masters in Biology Education at the Postgraduate Program at Universitas Negeri Semarang in 2016. Her research focuses on biology education, material teaching, learning media, science literacy. She has written and published book on education. She can be contacted at email: idah.hamidah@unwir.ac.id.

Aditya Fauzan was born in Sukabumi City, 20 May 2000. Received a Bachelor of Education from the Department of Biology Education at Wiralodra University, Indramayu. The author has been active as an educator at one of the Tutoring Institutions in Indramayu Regency since 2022-present. The author has been involved in lesson study activities in biology learning and is also active in several research activities in the field of biodiversity, such as the Biodiversity Baseline Assessment at PT. Pertamina Patra Niaga Balongan Indramayu and Bioconservation which will be carried out on Biawak Island, Indramayu Regency in 2023. The author can be contacted at email: fznaditya02@gmail.com.

Husamah is an assistant professor at Department of Biology Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Malang. He graduated with a bachelor's degree in Biology Education at Muhammadiyah University Malang in 2008, a Masters in Biology Education at the Postgraduate Program at Universitas Negeri Malang in 2014, and doctoral education in Biology Education at Universitas Negeri Malang (2023). He has conducted a lot of research in the fields of education in biology, ecology, environmental science, and the integration between environmental science and education (including environmental literacy, educational for sustainable development, and spirituality). He has written and published many books and articles on education and ecology/environmental science. He can be contacted at email: usya_bio@umm.ac.id.