

Development of Two-Tier Multiple-Choice Test to Assess Students' Conceptual Understanding on Respiratory System Material of 11th Grade of Senior High School

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Abstract. Students' conceptual understanding on Respiratory System Material has to be assessed. This is a research and development study aims to develop a two-tier multiple-choice (TTMC) test to assess students' conceptual understanding on Respiratory System Material on 11th grade. Modified Borg and Gall's (R&D) research design was used in this research. A preliminary study was conducted to analyse teacher and student needs about instrument assessment. Instrument validation was carried out to expert judgment and 90 of 11th grade students of SMA N Gondangrejo were selected by random sampling. The validation result shows that validation of material, construct, and practitioners expert are very good. Statistical validation using Rasch model shows that there is no item bias in terms of gender, 20 items are valid, person reliability 0.73, item reliability 0.89, item difficulty divided into four categories (very easy, easy, hard, very hard), and based on person separation and item separation the TTMC instrument was developed consists of 4 categories items to assess 3 categories respondent (understanding, misconception, not understanding). The percentage of students' conceptual understanding on Respiratory System Material shows that 37,7% students understood the concept, 41,6% students had misconceptions, and 20,7% students who don't understand the concept.

Keywords: Conceptual Understanding, Instrument Test, Rasch Model, Respiratory System Material, Two Tier Multiple Choice

1. Introduction

Education consists of learning and teaching activities. Learning and teaching activities must be prepared carefully in order to reach the learning objectives. Learning objectives are description of the expected performance of students after studying of the material being taught [1]. One of the learning objectives in the Biology subject is that students are able to understand the interrelated concepts of Biology. One of the efforts that can be done to assess the achievement of Biology learning objectives is by looking at the results of the student's National Examination in Biology subjects.

National Examination score of Senior High School level on Biology subject in 2015, 2017, and 2019 were still below in the minimum completeness standard, where the percentage of students who answered correctly was still below 55% [2]. One of the

reasons for the low score of the Biology National Examination was due to the lack of students who answered correctly on several materials, one of it is the respiratory system material. The results of Biology National Examination in the 2015, show that the percentage of students who answered correctly on the respiratory system material was 46.92%, in 2017 it was 38.62%, and in 2019 it was 36.86% [2]. The results of the Biology National Examination on respiratory system material in Central Java on 2015, 2017, and 2019 are also still below the minimum completeness standards. In 2015, the result of Biology National Examination showed that the percentage of students who answered correctly on the respiratory system material was 45.62%, in 2017 was 39.68%, and in 2019 was 46.47% [2].

The low results of the Biology National Examination of respiratory system material in Indonesia influenced by several factors. One of them is students' conceptual understanding on the respiratory system material is still low. Complex structure of the material, abstract of the material concepts, and using many scientific language, can cause difficulties for students to understand the concept [3].

Conceptual understanding can defined as learning with understanding [4]. Conceptual understanding include of relation, assimilation, comparison, and re-organization some new knowledge with existing knowledge and transferring it to solve the new daily problem. Conceptual understanding commonly based on the re-organizing the new concept with the existing concept. It was based on propose from some expert in cognitive constructivist theory [5,6,7]. Conceptual understanding has important role in the teaching and learning process because it is used as a basis for achieving learning outcomes [8]. Students' conceptual understanding can used to solve problems related to the concepts being studied, as well as a foundation for learning other related concepts [9]. Meanwhile, a lack of conceptual understanding in students can lead to misconceptions, even not understanding the concepts being taught, so that students' cognitive learning outcomes are not optimal [8].

Assessing students' conceptual understanding on respiratory system material can be done by conducting an assessment in the form of a written test on the material. Based on the results of a preliminary study with interview to a biology teacher in 11th Science at SMA N Gondangrejo, the form of questions that teachers usually used to conduct assessments are conventional multiple-choice and essays. Conventional multiple-choice questions have some advantages, such as technically easy to answer and easy in scoring, but also have disadvantage, like giving students opportunity to guess the answers [10]. Meanwhile, essay questions has advantages, like easy in the construct, but also has weaknesses, such as has tendency to subjectivity in scoring, takes time to correct the answers, and usually has small quantities of questions so it cannot cover all of material [10].

To know students' conceptual understanding on respiratory system material, needed an appropriate instrument test. There are many ways to know students' conceptual understanding, such as by interview, concept map, or with written test in the form of Two-Tier Multiple Choice (TTMC) Test [11]. TTMC test has better advantage than

conventional multiple choice and essay test. By using TTMC test, can decrease the error of measuring and minimize student's answer by guessing [8,9,10].

TTMC test that used in this study refers to the form of TTMC questions compiled by Treagust [14]. TTMC is an objectives test with two tier of questions. The first tier is the main question which contain a question and answer choices and the second tier contains the reasons for the answers in the first tier. By using a TTMC test, the chance for students to guess the answer is very small, so TTMC is more effectively used to find out students' conceptual understanding than conventional multiple choice questions [11]. The conventional multiple choice test give some opportunities for student's to guess the answer, whereas in the TTMC, students are declared to understand the concept and get a full score if the answer in the first tier and second tier are correct, so they cannot guess the answer yet [15]. Students' answers can give some information for teacher about students' conceptual understanding on respiratory system material, which are categorized into understanding concepts, misconceptions, or not understanding concepts [16].

Based on this explanation, it is necessary to conduct research in the form of development of TTMC test to assess students' conceptual understanding on the respiratory system material for 11th grade of Senior High School. The research problem in this study are :

- a. How are the qualities of TTMC test has been developed?
- b. How are the student's conceptual understanding profile on Respiratory System material through a TTMC test has been developed?

2. Research Methodology

2.1. Sample

This research was conducted at SMA N Gondangrejo, addressed in Jl. Solo-Purwodadi, KM. 11, Karanganyar Regency, Central Java. The research subjects consisted of 1 expert lecture in respiratory system material, 1 expert lecture in instrument evaluation, 2 practitioners expert, Biology teachers of SMA N Gondangrejo as instrument user, and students of 11th Science 1, 2, and 3 on the academic year 2019-2020.

2.2. Procedure

This study is research and development (R&D) research which refers to modified steps from Borg & Gall (1983) [17]. The first step is preliminary study which aims to determine students and teachers needed about instrument evaluation, and study literature about some research which is relevant to this research. The second steps are early product development which consisted of planning, including the stages of determining the test purpose, determining the material being tested, compiling the question grid, determining the number of questions, and developing the initial product. The third steps are expert validation and product revision of the TTMC test instrument has been developed. The items of TTMC test that has been declared valid by experts were tested to the students via Google Form feature, because the learning system during Covid-19 pandemic must be

done by online. The trial stages include preliminary trial, main field test, and operational field test.

2.3. Data Collecting

Data collection techniques were carried out by using non-test (consists of giving questionnaire for preliminary studies to know what are teachers and students needed about instrument evaluation, giving questionnaire for expert validation) and test (answering the TTMC test has been developed). The items of expert validation questionnaire and the interpretation of the validation result scores using the items in the questionnaire validation of the TTMC test instrument [18]. Scoring technique on the TTMC test is based on the students answer on the first tier and the second tier. Score “1” was given for the correct answer, while score “0” was given for false answer or not answered question [16]. The scoring technique for the TTMC test shown in Table 1 below.

Table 1. Interpretation of Score in TTMC test [16]

Answer Options		Score	Interpretation
Tier First	Tier Second		
Right	Right	2	Understanding Concept (UC)
Right	False	1	Misconception (M)
False	Right	1	Misconception (M)
False	False	0	Not Understanding Concept (NUC)

2.4. Data Analysis

2.4.1. Analysis of TTMC quality.

The result of expert judgment are analyze using formula (1). The calculation result shows the percentage of students who understand the concept, misconceptions, and do not understand the concept.:

$$N = \frac{k}{Nk} \times 100\% \quad (1)$$

Explanation :

N : result of percentage

k : obtained score

Nk : maximum score

Table 2. Interpretation Criteria Of Expert Validation Score [18]

Presentasi (%)	Kriteria
$86\% \leq N < 100\%$	Very Good
$72\% \leq N < 85\%$	Good
$58\% \leq N < 71\%$	Enough
$44\% \leq N < 57\%$	Lack
$N \leq 44\%$	Very Lack

Meanwhile, the result from statistical validation are analyze using Rasch model, include item bias, item validity, reliability, item difficulty, and differential power.

2.4.2. Analysis Of Student Conceptual Understanding Profile

Based on the interpretation data, the percentage of students' understanding of each concept is calculated using formula (2) below:

$$PKJ = \frac{n_1}{N_s} \times 100\% \quad (2)$$

Explanation :

PKJ : result of percentage

n_1 : quantity of student conceptions (UC, M, NUC)

N_s : total sample

3. Result of Research

3.1. Quality of Two Tier Multiple Choice (TTMC) Test

20 items of TTMC to assess student conceptual understanding on Respiratory System material has been developed. Example of TTMC test item has been developed as shown by Figure 1. below.

1. Rama melakukan petualangan mendaki Gunung Merbabu. Ia merasa tubuhnya mulai mengalami gangguan pernapasan ketika telah mencapai ketinggian lebih dari 1800 mdpl. Gangguan pernapasan yang seringkali terjadi pada para pendaki gunung terkait dengan ketinggian suatu tempat yaitu
 - a. Kesulitan bernapas akibat penyempitan saluran napas yang bersifat sementara.
 - b. Mekanisme pernapasan terganggu karena tubuh menggigil.
 - c. Kesulitan bernapas karena tiupan angin yang kencang.
 - d. Sesak nafas sehingga frekuensi pernapasan meningkat.
 - e. Bersin dan hidung tersumbat karena paparan allergen.

Alasan :

- a. Semakin tinggi suatu tempat dapat menyebabkan mengendurnya otot-otot faring, sehingga otot-otot pernapasan tidak dapat berkontraksi ketika inspirasi.
- b. Semakin tinggi suatu tempat, kadar oksigen yang ada di lingkungan semakin rendah, sehingga kadar oksigen yang dihirup menjadi lebih sedikit.
- c. Semakin tinggi suatu tempat, udara yang semakin dingin menyebabkan tubuh menggugil, sehingga menghambat pernapasan.
- d. Semakin tinggi suatu tempat, suhu lingkungan semakin dingin, sehingga dapat memperlambat kecepatan pernapasan.
- e. Semakin tinggi suatu tempat dapat menyebabkan sulitnya pengeluaran CO₂ dari paru-paru.

Figure 1. Example of TTMC Test has been Developed

3.1.1. Expert Judgment of TTMC Test

TTMC test has been validated by material expert, instrument evaluation expert, and practitioners expert. The results of expert validation show that validation of content are 97.79% (very good), validation of construction 89.93% (very good), and validation of practitioners are 97.76% (very good). After validated by experts, valid items were tested on students in the preliminary field trial.

3.1.2. Preliminary Field Test

Preliminary field test was carried out by 2 Biology teachers and 10 students of 11th science. The teacher serves to assess the readability and correctness of the concept in the

TTMC test has been developed, while the students answer used to find out if there are biased items using Rasch analysis. The results of teacher judgment about TTMC tes has developed shows that the average score of all indicators is 85.73%, which is included in “Good” category (B). Result of statistical analysis to detect the bias items are shown in the Figure 2. below.

Person CLASSES	SUMMARY DIF CHI-SQUARE	D.F.	PROB.	BETWEEN-CLASS MEAN-SQUARE	t=ZSTD	Item Number Name
2	.2822	1	.5952	.1584	-.5021	1 Q1
2	1.8425	1	.1747	1.1906	.5984	2 Q2
2	.5401	1	.4624	.3162	-.2047	3 Q3
2	.5401	1	.4624	.3162	-.2047	4 Q4
2	.1822	1	.6695	.1054	-.6480	5 Q5
2	.1553	1	.6935	.0823	-.7272	6 Q6
2	2.9375	1	.0865	2.0773	1.0568	7 Q7
1	.0000	0	1.0000	.0000	.0000	8 Q8
2	.0179	1	.8936	.0102	-1.1892	9 Q9
2	.0231	1	.8791	.0129	-1.1519	10 Q10
2	.0000	1	1.0000	.0003	-1.5134	11 Q11
2	.3347	1	.5629	.1954	-.4190	12 Q12
2	2.9811	1	.0842	2.1807	1.1010	13 Q13
2	.7823	1	.3765	.4580	-.0147	14 Q14
2	1.9441	1	.1632	1.2337	.6252	15 Q15
2	.2822	1	.5952	.1584	-.5021	16 Q16
1	.0000	0	1.0000	.0000	.0000	17 Q17
2	.3347	1	.5629	.1954	-.4190	18 Q18
2	1.0717	1	.3006	.6601	.1971	19 Q19
2	.1565	1	.6924	.0888	-.7035	20 Q20

Figure 2. Result of Detection for Item Bias using Rasch Analysis

Item declared biased if they have probability value less than 5% [19]. Based on Figure 1, we know that all of item have probability value more than 5%, so there is no item biased in term of gender. Therefore, no item revision needed.

3.2. Main Field Test and Operational Field Test

The main field test was carried out on 28 students and operational field test were carried out on 52 students to determine the statistical validity of the questions, reliability, item difficulty, and Differential power of the questions which were then analyzed using the Rasch model. The result are:

3.2.1. Statistical Validity

Criteria for items are valid and acceptable if the item has met at least one of the three validity criteria, there are MNSQ value ($0.5 < \text{MNSQ} < 1.5$), ZSTD value ($-2 < \text{ZSTD} < 2$), and Pt. Mean Corr ($0.40 < \text{Pt. Mean Corr} < 0.85$) [19]. Therefore, based on the main field test and operational field test, all items can be maintained, so did not need item revision.

3.2.2. Reliability

Person reliability and item reliability of the TTMC test instrument has been developed is shown in Table 4. as follows:

Table 3. Reliability

Trial Stages	Person Reliability	Item Reliability
Main Field Test	0.80 (Enough)	0.88 (Very good)
Operational Field Test	0.73 (Enough)	0.89 (Very good)

Person Reliability on the main field test and operational field test showed that the TTMC test has been developed is enough, and the item reliability of both test are good, so it could be interpreted that the consistency of respondents answer was weak, but the quality of the items was good.

3.2.3. Item Difficulty

Item difficulty in the Rasch model grouped into four categories, there are, very easy item (measure value <-1), easy item (measure values -1 to 0), difficult item (measure value 0 to 1), and very difficult item (measure value > 1) [19]. The percentage item difficulty of the TTMC test has been developed shown in Table 4. as follows:

Table 4. Percentage of TTMC Test Instrument Difficulty Level

Level of Difficulty	Main Field Test	Operational Field Test
Very easy	20%	10%
Easy	15%	30%
Difficult	55%	55%
Very difficult	10%	15%

3.2.4. Differential power

Differential power is the ability of an instrument test to distinguish students based on their level of ability [20]. In Rasch analysis, differential power can be seen from the value of item separation and person separation. The greater value of separation, the quality of the instrument has been developed are better [19]. Differential power shown in Table 5 below:

Table 5. Differential power of TTMC Test Instrument

Trial Stages	Person Separation	Item Separation
Main Field Test	2.03	2.68
Operational Field Test	1.63	2.89

The value of separation should be calculated by the formula:

$$H = \frac{[(4 \times SEPARATION)+1]}{3}$$

The result of the calculation of the item separation at the main field test stage is 3.9 (rounded to 4) and the result of the calculation of the person separation is 3.04 (rounded to 3). The calculation result of item separation on the operational field test is 4.18 (rounded to 4). Meanwhile, the calculation result of person separation is 2.51 (rounded to 3). Based on the results, it can be seen that the TTMC test instrument developed has a constant value of person separation and item separation. In both the main field test and operational field test, the TTMC test instrument developed consisted of 4 groups of questions (very easy, easy, difficult, and very difficult) and 3 groups of respondents (did not understand the concept, misconceptions, and understood the concept).

3.3. Student Conceptual Understanding Profiles on Respiratory System Material through a TTMC Test

Analysis of students' conceptual understanding on respiratory system material using the TTMC test instrument developed is shown in Table 6 as follows:

Table 6. Analysis of Students' Conceptual Understanding

Level of Concept Understanding	Percentage (%)
Understanding the Concept (PK)	37.7
Misconception (M)	41.6
Do not understand the concept (TPK)	20.7

Based on the analysis, it can be seen that the percentage of students who understand the concept as much as 37.7%, the percentage of students who experience misconceptions as much as 41.6%, and the percentage of students who not understand the concept as much as 20.7%. The distribution of students' conceptual understanding on the respiratory system material for each concept is shown in Figure 3. as follows:

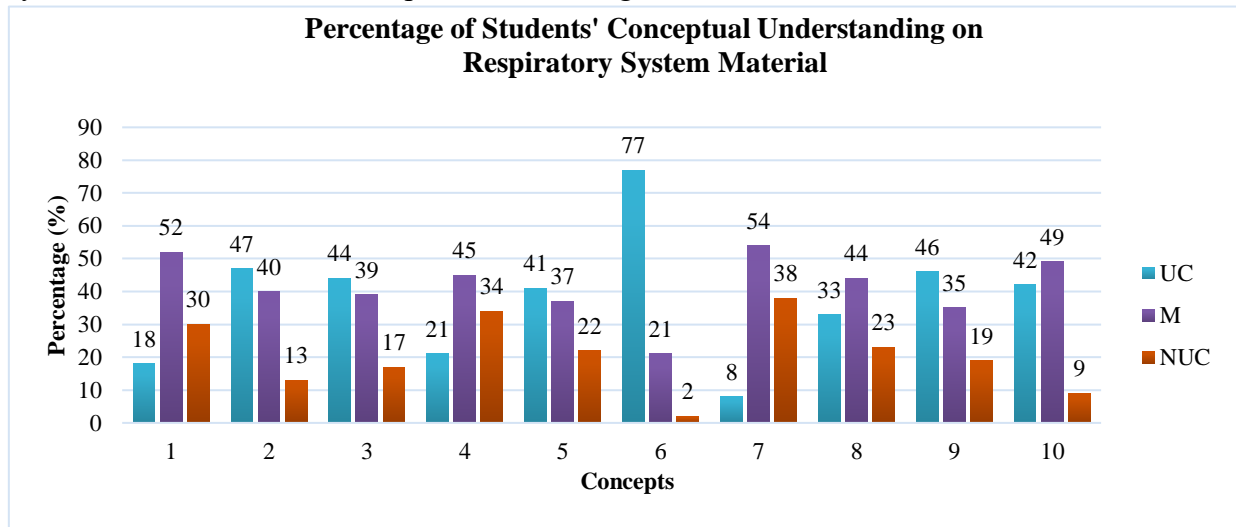


Figure 3. Percentage of Students' Conceptual Understanding on Respiratory System Material

Information :

UC: Understanding Concept, M: Misconception, NUC: Not Understanding Concept, 1st concept: Structure and Function of Respiratory Organs, 2nd Concept: Respiratory Mechanism, 3rd Concept: Breathing Mechanism, 4th Concept: Transport and Exchange of Gases, 5th Concept: Volume of Breathing in Human Lungs, 6th Concept: The Dangers of Cigarettes for Health, Concept 7th: Effect of Air Pollution on the Respiratory System, Concept 8th: Disorders of the Respiratory System, Concept 9th: Respiratory System Technology, Concept 10th: Respiratory Organs in Animals.

Based on the Figure 2., it can be seen that students understood the most concepts occurred in the dangers of smoking to health concept as much as 77%, while students understood the concepts least occurred in the concept of effect of air pollution on the respiratory system, as much as 8%. The biggest misconception occurred in the concept of the Effect of Air Pollution on the Respiratory System, where students who experienced misconceptions were 54%, while the least misconceptions occurred in the concept of the Danger of Smoking to Health, amounting to 21%. Most students who not understood the concepts occurred in the concept the effect of air pollution on the respiratory system was 38%, while students at least not understood the concept occurred in the concept of the dangers of smoking to health as much as 2%.

4. Discussion

The results of expert validity as well as the results of statistical validity on the TTMC test instrument developed obtained 20 items were suitable for use. Question items consist of 10 concepts on respiratory system material. The quality of the TTMC test developed in terms of validity, reliability, difficulty level, and differential power. The validity of TTMC has been developed consists of validity from expert judgment and statistical validity. Expert validity is carried out on material experts, instrument evaluation experts, and practitioners expert. The results from the material expert obtained an average aspect score as much as 94.79%, so it belongs to category very good. The results of construct validation by evaluation instrument expert, obtained an average aspect score as much as 89.93%, so it belongs to category very good. The results of the expert practitioners obtained an average aspect score as much as 97.67%, so it belongs to “very good” category. Based on the three experts judgment, there are several suggestions to improve until produced a final product of TTMC test instrument that is ready to be tested on students.

The results of statistical validation are used to determine the value of validity, reliability, item difficulty, and differential power of the TTMC test instrument developed. The results of data analysis in the main field test and operational field test showed that : (a) 20 items were valid (b) Person Reliability on the main field test and operational field test showed that the TTMC test has been developed is enough, and the item reliability of both test are good, so it could be interpreted that the consistency of respondents answer was weak, but the quality of the items was good. (c) The item difficulty of the questions consists of four categories (very easy, easy, difficult, and very difficult), so the TTMC test has been developed can assess the students' conceptual understanding in different level difficulties. (d) The value of differential power can be seen on item separation and person separation, shows that the TTMC test instrument developed consists of 4 item categories (very easy, easy, difficult, and very difficult categories) which are used to identify 3 groups of respondents (understand concepts, misconceptions, and not understand concept).

Based on Table 7, it can be seen that the percentage of students who understand the concept of Respiratory System Material as much as 37.7%, the percentage of students who had misconceptions as much as 41.6%, and the percentage of students who didn't understand the concept as much as 20.7%. Based on the distribution of students' conceptual understanding on respiratory system material on Figure 2, we know that students most understand in the concept of Dangers of Smoking to Health with percentage as much as 77%, while student least understand in the concept of effect of Air Pollution On the Respiratory System with percentage as much as 8%. The biggest misconception occurred in the concept of Effect of Air Pollution on the Respiratory System, where students who had misconceptions as much as 54%, while the least misconceptions occurred in the concept of the Danger of Smoking to Health as much as 21%. Students most didn't understand in the concept of Effect of Air Pollution On The Respiratory

System with percentage as much as 38%, while students least didn't understand in the concept of Dangers Of Smoking To Health with percentage as much as 2%.

Based on the results of the analysis, there were still students who had misconceptions or did not understand the concepts in each respiratory system concepts had been tested. Students who had misconceptions occupy the largest percentage, as much as 41.6%. Students commonly could not know what is the "Black Lung" disease and what causes it. Students gained their knowledge about Respiratory System from their daily life, and then students come to the class with different knowledge that is built. It may causes students' initial conceptual understanding are variously and in the some concept may be wrong [21]. Therefore, teachers need to find out students' conceptual understanding, so that teachers can develop learning strategies to optimize students' conceptual understanding of the material being taught.

TTMC test more efficiently used to assess students' conceptual understanding than conventional multiple-choice test, because the form of TTMC questions is able to minimize students guessing the answer [16-17]. Another advantage of the TTMC test instrument if compared with essay test are TTMC test can be used quickly, easy scoring in techniques, efficient in time, and the answers not depend on students' writing skills [23]. Besides that, TTMC test can minimize students to guess the answers, because there is second tier which contains the reasons why students choose answers in the first tier [11][24]. The test results can used by the teacher as a reference to assess students' conceptual understanding about respiratory system material. Students' conceptual understanding can be categorized into three groups, there are understanding concepts, misconception, and not understanding concepts. By using TTMC, teachers can find out students who understand the concepts, students who have misconceptions, and students who do not understand the concept of respiratory system material.

5. Conclusion

The results of this study show that : (1) The quality of TTMC test has been developed is appropriate to use, with the following details : (a) 20 items of TTMC to assess students' conceptual understanding of the respiratory system material are valid. The results of the validation of material expert is very good, construction expert is very good, expert practitioners are very good. (b) The results of statistical validation with Rasch analysis include the values of validity, reliability, item difficulty, and differential power, meet the criteria as an instrument test suitable for use. (2) The profile of students' conceptual understanding shows that students who understand the concepts in the respiratory system material as much as 37.7%, students who had misconceptions as much as 41.6%, and students who do not understand the concepts as much as 20.7%.

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