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Biology science learning continuum at the elementary school level based on teachers' cognitive abilities

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ABSTRACT

This research aims to develop a biology science learning continuum on the aspects of structure and function at the elementary school (ES) level based on the teachers' cognitive abilities. This survey research used a reasoned multiple-choice test, having the material aspects of structure and function with the cognitive levels of C1-C2, was developed by listing the key sub-aspects, forum group discussion, item development, expert judgement, and item revision. The test was administered to 240 ES teachers in the Special Region of Yogyakarta, Indonesia, and the results were analyzed through the Quest program. The results reveal that the learning continuum is developed based on the difficulty level of the questions in which item response theory (IRT) shows the respondents' cognitive ability, the level of cognitive processes from the lower level to the higher ones, the complexity level from the simple to the most complex in each sub-aspect of the structure and function. The sub-aspects with higher cognitive ability scores, lower difficulty index, lower level of cognitive processing, and lower complexity are recommended to at the lower grades. Sub-aspects with lower cognitive ability value, higher difficulty index, higher level of cognitive processing, and higher complexity category are recommended to the higher grades.

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1. INTRODUCTION

Curriculum is an educational program that contains a series of planned and structured activities that refer to the graduate competency standards, content standards, process standards, and assessment standards [1]. It is designed to provide as much learning experience for the students as possible to develop their attitudes, skills, and knowledge needed to develop their competencies. It provides opportunities for the students to integrate their knowledge and ultimately generate enhanced learning experiences [2]. The curriculum structure is determined based on the National Education Standards which aim to regulate every aspect of competencies, including the learning materials learned at every educational level. This structure consists of objectives, contents (teaching materials), strategies, learning resources, time allocation, infrastructure, and other components that support the learning activities [3]. The structure of the curriculum should adhere to the principles of learning continuum, so that the teaching materials given to the students do not overlap and are adjusted to their cognitive and mental development.

Besides, characteristics, scope, and depth of the teaching materials must be adjusted to the learning continuum so that the learning process becomes more effective in achieving the expected competency mastery. Therefore, the blueprint for the teaching material's structure in the form of a learning continuum is

very important to be developed as a guideline in curriculum development. In regard to this, it is important to prepare the teaching materials based on the students' readiness in terms of their developmental level by organizing them in such ways that they become interesting to learn and can be effectively implemented [4]. Preparing appropriate teaching materials based on the students' development can promote their active participation in their own learning atmosphere, make them aware of their progress and development, help them to manage knowledge, and obtain the necessary competencies to adapt to rapidly and sometimes unexpected environmental changes [5].

A learning continuum generally shows vertical continuity between the level of competence and the characteristics of teaching materials at each educational level [6]. It has many benefits in the learning process, some of which include acting as the basis in appropriately choosing the learning materials and resources for varied levels of the students, developing individual or group learning, and developing further lesson plans, and developing the curriculum [7], [8]. Besides, it is also harnessed to create programs and services to build the knowledge and skills needed by the learners, create continuous learning opportunities, and improve their organizational dynamics and capacity to continue to adapt to the current rapid environmental changes [9]. The basic concept of the learning continuum is established by mapping some of the competencies that have correlations at every level, from the simplest to the most complex, from the easiest to the most difficult, and from the most concrete to the most abstract [10]. Ideally, the materials presented by the teachers in the curriculum should match the level of competence with some sub-aspects or learning materials, and pay attention to the students' development [11]–[14]. The teaching materials, therefore, should obey the rules stipulated in the learning continuum conforming to the students' development on both cognitive and mental aspects to make possible a more directed, effective, and efficient learning process [15].

Cognitive ability is the capacity possessed by a person to reason, think, solve problems, and learn. It is considered as one of vital features affecting achievement in education and work [16]. Regarding this, Anderson and Krathwohl divide these cognitive abilities into six levels, namely remembering (C1), understanding (C2), applying (C3), analyzing (C4), evaluating (C5), and creating (C6) [17]. Besides, teachers' cognitive talents have been proven to have a significant impact on the intellectual development of their students. In other words, cognitive and pedagogic abilities or competencies of teachers can activate learning, and this subsequently impacts on student achievement [18]. At least two studies show that teachers' cognitive abilities in mastering content have a strong influence on student achievement [19], [20] Cognitive competencies possessed by teachers, therefore, can be used to predict student performance [21]. On the other hand, competencies that are not mastered by teachers will be less likely to be mastered by students [22]. Therefore, the cognitive abilities of teachers can be one of the bases for constructing the learning continuum.

One of the competencies that must be achieved by students in elementary schools in biology learning is cognitive competence. C1-C2 cognitive levels are required to be mastered by elementary school students according to the age and mental development of students [23]. Concerning this, Piaget's theory of cognitive development states that children actively build their understanding of the world through four stages of cognitive development, namely the sensorimotor (0-2 years), pre-operational (2-7 years), concrete operational (7- 11 years), and formal operational stage (11 years - adults) [24], [25]. ES students aged 7-12 years old, accordingly, have been able to think logically using their reasoning [3]. In addition to the level of knowledge, the learning process should also consider the dimensions of knowledge which consist of four categories, namely factual, conceptual, procedural, and metacognitive. The series of learning in the curriculum structure, therefore, should be carefully organized from the concrete (factual) to abstract (metacognitive) [3].

Biology as embedded in the science subject is taught in the ES curriculum. According to the Biological Science Curriculum Study (BSCS) [26], biology has a scientific scope that includes biological objects, themes and problems, and levels of life organizations. The scope is united into one unit in biology learning. One of the themes and issues studied in biological science is the bodily structure and function discussing the interrelationship of the body structure of living things and their respective functions. These structure and function materials should be appropriately arranged according to the learning continuum so that the target of students' cognitive mastery can be achieved according to their cognitive development.

In fact, the biology science curriculum applied at schools and practiced by the teachers has so far contained some overlapping aspects, is likely incompatible with the students' cognitive development, and even some materials are not well arranged from easy to difficult, simple to complex, and concrete to abstract. These, therefore, may result in an ineffective teaching-learning process [27]. Therefore, it is necessary to develop a curriculum based on the learning continuum whose competencies are developed according to the cognitive development of students, or organized from easy to difficult, simple to complex, and concrete to abstract. The curriculum developed based on the learning continuum will lead to optimal achievement of all students. Therefore, the current study aimed at developing a learning continuum on aspects of structure and

function by administering a cognitive ability test to its respective teachers. The results of teachers' cognitive ability test in each sub-aspect of the material were later used as the basis for developing the learning continuum of that biology topic to be taught at the elementary school level.

2. RESEARCH METHOD

This is survey research aimed to determine the cognitive abilities of the elementary school teachers which would be used for the preparation of the biology learning continuum on the aspects of structure and function. The population was hypothetically selected, consisting of all elementary school teachers in the Special Region of Yogyakarta, Indonesia. This selection was made because the province of the Special Region of Yogyakarta has the best education index in Indonesia and collecting data from this area is feasible in this research context. The sample members were selected through convenience sampling, including 240 public and private ES teachers in the Special Region of Yogyakarta, Indonesia with the following details: Gender (female=180, male=60), employment status (Civil Servant=120, non-Civil Servant=120), latest education (undergraduate=229, graduate=11), teaching level (grade 1=41, grade 2=31, grade 3=37, grade 4=33, grade 5=52, grade 6=46), teaching experience (0-5 years=72, 6-10 years=51, 11-15 years=50, 16-20 years=31, >20 years=36).

The instrument used in this research was a cognitive ability test in the form of reasoned multiple-choice questions. Before the cognitive test questions were developed, the researchers first listed all of the sub-material aspects of structure and function, then a forum group discussion (FGD) was conducted with the ES teachers from grade 1 to 6. This FGD was carried out prior to the development of the cognitive test. The FGD was conducted to determine which sub-aspects of the structure and function that could be delivered to the ES students. The main aspects of the considerations were the cognitive level, the depth of the material, and the students' mental development. Based on the results of the FGD, there were 15 sub-aspects of the material that could be taught at the elementary school level. Then, from the 15 selected material sub-aspects, a questionnaire was made and 30 questions - each sub-aspect consisted of 2 questions with C1 and C2 cognitive level - were then validated by an expert which was a lecturer of biology education at Yogyakarta State University. Based on the results of the validation, further improvements were made to some items in terms of language and content, so that they were declared valid. After the cognitive test instrument in the sub-aspects of structure and function was revised based on the expert's assessment results, the data collection was then carried out by providing an online test for the ES teachers in five regencies in the Special Region of Yogyakarta, Indonesia, which was conducted in April 2020.

The analysis of the test items for the teachers' cognitive abilities was done by using the Quest program. After the items were declared fit to the model, a learning continuum of structure and functions was carried out orderly based on the difficulty level of the questions (in IRT, it showed the ability). It was then proceeded with the sorting of cognitive process levels starting from C1 to C2 which was also based on the complexity of the materials, from simple to complex ones.

3. RESULTS AND DISCUSSION

3.1. Results

The results of this research are in the form of the results of the cognitive abilities test item analysis on the aspects of structure and function developed by the researchers and the learning continuum on the aspects of structure and function based on the ES teachers' cognitive abilities. Firstly, the analysis results on the cognitive ability test using the Quest program are presented in Figure 1 and Figure 2. Figure 1 shows the distribution of test items based on their compatibility with the model. The parameter used is INFIT MNSQ. The two vertical dots indicate the range of the MNSQ INFIT values obtained, which is between 0.77 and 1.30 [28]. Based on the data, it is clear that the 30 questions of the cognitive ability test in the aspects of structure and function developed by the researchers are valid/fit according to the Rasch model, because they have an INFIT MNSQ value between 0.77 and 1.30.

Figure 2 shows a map of the items and the subjects of ES teacher cognitive ability tests. The right side contains the item number, while the left one is the subject distribution, where each cross represents 50 subjects. The distribution of the items and subjects is arranged on the same scale so that in general, the existing items with lower difficulty index than the subject's ability can be identified. Item number 14 is the most difficult, while question number 1 is the easiest one. The difficulty level of each question can be seen from the Threshold value (b value) as presented in Table 1. The structured learning continuum construct is presented in Table 2.

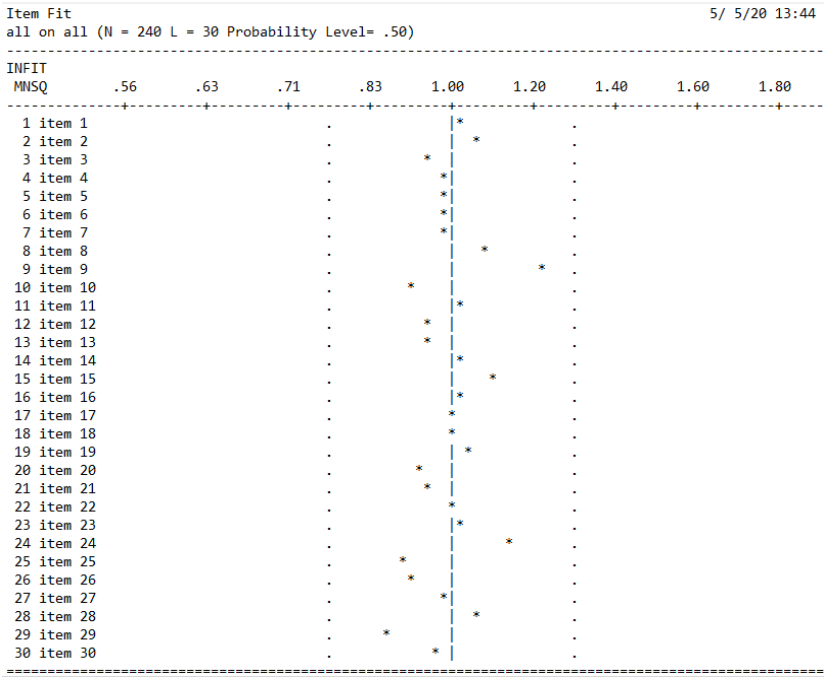

Figure 1. Distribution of cognitive ability test items based on the compatibility with the model

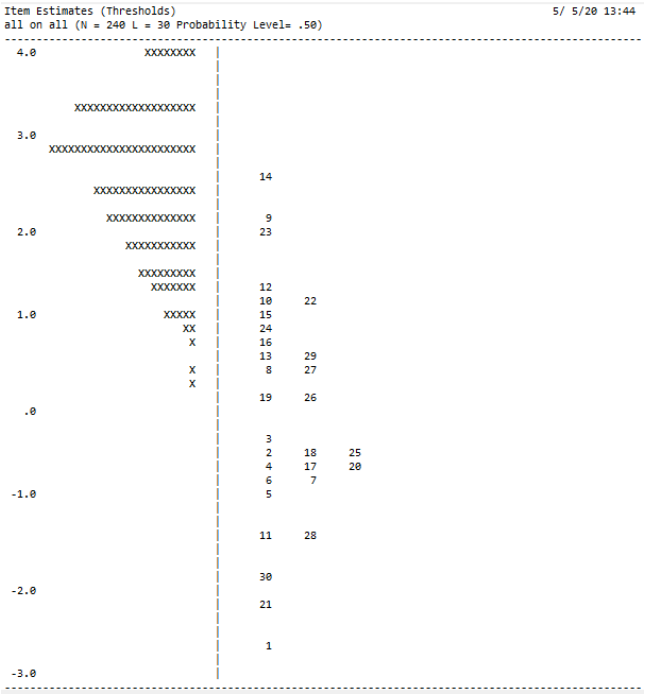

Figure 2. Map of items and elementary school teachers' cognitive ability test

Table 1. Thresholds' value criteria (b value) items of the cognitive ability tests for elementary school teachers

Threshold value	Criteria	Total item
b > 2	Very difficult	2
1 < b ≤ 2	Difficult	5
-1 < b ≤ 1	Medium	18
-1 < b ≥ -2	Easy	3
b < -2	Very easy	2

Table 2. Learning continuum of the aspects of structure and function at the elementary school level

Item No.	Sub-aspects of structure and function	Complexity	Cognitive process level	Item difficulty index	Teachers' cognitive abilities (%)
1	Morphological structure of the human body and its functions	Simple	C1	-2.59	99.17
21	Factors affecting the morphological structure of the flowering plants and its functions	Simple	C1	-2.19	98.75
30	Factors affecting the anatomical structure of flowering plant organs (roots, stems, leaves, flowers, fruit and seeds) and its functions	Simple	C1	-1.90	98.33
11	Factors affecting the anatomical structure of human and animal organ systems and its functions	Simple	C1	-1.34	97.08
28	Factors affecting the anatomical structure of the organs composing human and animal organ systems and functions	Simple	C1	-1.34	97.08
5	Morphological structure of the flowering plants and its functions	Rather complex	C1	-0.97	96.25
7	Morphological structure of the flowering plant organs (roots, stems, leaves, flowers, fruit, and seeds) and its functions	Rather complex	C1	-0.87	94.58
6	Factors affecting the morphological structure of the flowering plants and its functions	Rather complex	C2	-0.78	95.42
20	Morphological structure of flowering plants and its functions	Rather complex	C2	-0.69	94.17
17	Morphological structure of animals and its functions	Rather complex	C1	-0.69	93.75
4	Morphological structure of human and animal organs (head, neck, body, locomotion) and its functions	Rather complex	C1	-0.62	93.33
18	Morphological structure of human and animal organ systems and its functions	Rather complex	C1	-0.54	93.75
2	Morphological structure of animals and its functions	Rather complex	C2	-0.47	93.33
25	Anatomical structure of organ systems (nerve, motion, blood circulation, digestion, respiration, excretion, reproduction, endocrine, and immunology) in humans and animals and its functions	Rather complex	C1	-0.47	93.33
3	Morphological structure of human and animal organ systems and its functions	Rather complex	C2	-0.41	92.08
19	Morphological structure of human and animal organs (head, neck, body, locomotion) and its functions	Rather complex	C2	0.16	88.33
26	Factors affecting the anatomical structure of human and animal organ systems and its functions	Rather complex	C2	0.20	86.25
27	Anatomical structure of organs that make up the organ systems (nerves, motion, blood circulation, digestion, respiration, excretion, reproduction, endocrine, immunology) of humans and animals and its functions	Rather complex	C1	0.43	85.42
8	Morphological structure of the ferns and its functions	Rather complex	C1	0.5	85.42
29	Anatomical structure of flowering plant organs (roots, stems, leaves, flowers, fruits and seeds) and its functions	Rather complex	C1	0.57	84.17
13	Factors affecting the anatomical structure of the organs composing human and animal organ systems and its functions	Rather complex	C2	0.66	80.83
16	Morphological structure of the human body and its functions	Rather complex	C2	0.81	81.25
24	Morphological structure of ferns (roots, stems, leaves, spores) and its functions	Rather complex	C1	0.98	77.5
15	Factors affecting the anatomical structure of the flowering plant organs (roots, stems, leaves, flowers, fruit and seeds) and its functions	Complex	C2	1.00	77.08
22	Morphological structure of the flowering plant organs (roots, stems, leaves, flowers, fruit and seeds) and its functions	Complex	C2	1.25	72.92
10	Anatomical structure of organ systems (nerve, motion, blood circulation, digestion, respiration, excretion, reproduction, endocrine, and immunology) in humans and animals and its functions	Complex	C2	1.25	71.67
12	Anatomical structure of the organs that make up the organ systems (nerves, movement, blood circulation, digestion, respiration, excretion, reproduction, endocrine, and immunology) of humans and animals and its functions	Complex	C2	1.39	71.25
23	Morphological structure of the ferns and its functions	Complex	C2	1.92	59.58
9	Morphological structure of the ferns (roots, stems, leaves, spores) and its functions	Complex	C2	2.13	55.83
14	Anatomical structure of the flowering plant organs (roots, stems, leaves, flowers, fruits and seeds) and its functions	Complex	C2	2.58	46.25

After analyzing the items, the learning continuum structure was then developed based on i) the difficulty level of the items which simultaneously shows the cognitive abilities; ii) the level of cognitive processes, from low to high level (C1-C2); and iii) the complexity, from the simplest to the most complex ones. Based on Table 2, it is known that the teachers' cognitive abilities in the sub-aspect of the morphological structure of the human body and its functions (level C1) has the highest value, 99.71%, with the difficulty index of -2.59 (very easy), while the teachers' cognitive abilities of the sub-aspect of the anatomical structure of flowering plant organs (roots, stems, leaves, flowers, fruits, and seeds) and its functions (level C2) has the lowest value, 46.25%, with the difficulty index of 2.58 (very difficult).

3.2. Discussion

As stated, this research attempts to generate a structural formulation of the biology science learning continuum on the structure and function aspects at elementary schools. Previous research has developed the biology science learning continuum on specific pedagogical learning materials by asking for the opinion and approval of teachers [3]. In addition, such learning continuum has also been developed based on the opinions of biology education experts [6], [27]. However, most biology teachers and education experts still argue that they follow the existing curriculum structure from the government, and sometimes there is no unanimous agreement between the teachers or experts about the allotment of certain materials taught at which class and cognitive level. This causes the structure of the learning continuum to be less effective to use, because there are some overlapping materials or competencies between the grades and educational levels.

The biology science learning continuum on the material aspects of structure and function developed in this research is based on the teachers' cognitive competencies. A teacher should have at least four basic competencies, namely professional, pedagogical, social, and personality competences. Professional competence requires the teachers to master the teaching materials well so that they can deliver the learning materials to their students. The teachers' cognitive knowledge of the learning materials can be determined by a cognitive ability test. When a teacher does not have good cognitive abilities regarding the materials, he will not be able to teach the materials optimally to the students. Therefore, the teachers' cognitive abilities on certain materials become a reflection of their abilities to deliver and teach their students. This is used by the researchers as a foundation to develop a learning continuum on biology science, specifically on the material aspects of structure and function.

The cognitive ability test developed in this research has been adjusted to the students' abilities at the ES level, which includes their abilities to remember (C1) and understand (C2). According to Juniati and Subali [29], the ES students can be taught concrete materials with competency levels of knowledge to remember (C1) and understand (C2). According to Anderson and Krathwohl [17], the dimension of knowledge to remember (C1) includes recognizing and recalling, while the dimensions of understanding knowledge (C2) include interpreting, exemplifying, classifying, summarizing, inferring (concluding), comparing, and explaining. For these, 30 questions have been developed from 15 sub-aspects of the structure and function materials selected and approved by the teachers during the FGD, and each sub-aspect consists of two questions representing the dimensions of memorizing (C1) and understanding (C2).

Concerning this test, the instrument used in this research is a reasoned multiple-choice question. According to Tüysüz [30], using such kind of instrument can reduce possibilities of the respondents guessing the correct answer to 4%, while in Rusilowati's idea [31], using the reasoned multiple-choice questions eases the researchers to find out which respondents answer the questions correctly with the proper reasons and those who answer correctly but providing incorrect reasons. Using the reasoned multiple-choice questions, the teachers who only guess the answers correctly can be found out easily.

The analysis of the items on the cognitive ability test was carried out to determine its quality. The distribution of the cognitive ability test items was done based on compatibility with the model into parameters. Figure 1 shows that all item items are accepted/fit according to the Rasch model with an INFIT MNSQ value of 0.77-1.30, which means that the instrument is valid to be used as a measuring tool (it is able to provide empirical information according to what is measured) [28]. In addition to compatibility with the model, Figure 2 shows a map of the items and the subjects' abilities which represent the distribution of questions that are difficult and easy to answer. The map of the items shows that item number 14 is the most difficult, while number 1 is the easiest one. The level of difficulty of the questions can be seen from the threshold value (b value) presented in Table 1. From Table 1, it is apparent that of the 30 valid questions, there are 2 items that fall into the very difficult category, 5 items are difficult category, 18 items questions in the medium category, 3 items in the easy category, and 2 items in the very easy category. This data shows the ideal ability of the test takers because the curve is normal where there are few test takers having both low and high abilities, most of them are categorized as moderate.

The learning continuum is structured based on the results of the teachers' cognitive test by looking at the difficulty level (the IRT shows the cognitive abilities), the level of cognitive processes, and the complexity (from the simplest to the most complex) as presented in Table 2. In Table 2, it can be seen that the highest teachers' cognitive abilities are achieved in the sub-aspect of the morphological structure of the human body and its functions with the value of 99.17% and the lowest difficulty index is -2.59 (very easy). The sub-aspect is included in the cognitive level C1 (remembering), and in the learning continuum, it is categorized as simple (low), because its achievement of the cognitive ability test is high. Meanwhile, the sub-aspect of anatomical structure of the flowering plant organs (roots, stems, leaves, flowers, fruits, and seeds) and its functions has the lowest cognitive ability score (46.25%) and obtains the highest difficulty index, 2.58 (very difficult). This sub-aspect includes in the C2 cognitive level (understanding) and is classified as complex because of its low cognitive ability value.

Table 2 shows that almost all of the sub-aspects related to morphology have high cognitive ability values compared to those related to anatomy. This corresponds to the level of complexity, difficulty, and abstraction of the material itself. Morphology discusses the structure of the outer parts of living things [32], while anatomy discusses the inner ones [33]. The material aspects of morphology are simpler, easier, and concrete than the anatomy, so that the sub-aspects of this material tend to have higher cognitive ability value than the anatomies.

However, not all sub-aspects in morphology obtain high cognitive ability values. There are some that have lower values, namely the morphological structure of the fern plant body and its functions with the cognitive ability value of 59.58% and difficulty index of 1.92 (difficult). The morphological structure of the ferns (roots, stems, leaves, spores) and its functions has a lower cognitive ability value, 55.83%, and item difficulty index of 2.13 (very difficult). The two sub-materials are included in the C2 cognitive level (understanding) with high complexity. At the ES level, it has been very rare for teachers to introduce the material about the ferns to young learners, so that it is more likely to be an uncommon topic compared to the functional structure of humans, animals, or flowering plants, so it is natural that this sub-aspect has lower cognitive ability value.

Besides, the sub-aspects of structure and function for anatomy tend to have low cognitive ability values. Table 2 reveals that the sub-aspect of the anatomical structure of the organ system (nerve, movement, blood circulation, digestion, respiration, excretion, reproduction, endocrine, and immunology) in humans and animals and its functions obtains a cognitive ability value of 71.67% with the difficulty index of 1.25 (difficult). Likewise, the sub-aspect of the anatomical structure of the organs that make up the organ system (nerve, movement, blood circulation, digestion, respiration, excretion, reproduction, endocrine, and immunology) of humans and animals and its functions also has lower cognitive ability value of 71.25% with the difficulty index of 1.39 (difficult). This is similar to the sub-aspect of the anatomical structure of the flowering plant organs (roots, stems, leaves, flowers, fruit and seeds) and its functions, which also has low cognitive ability value (46.25) with the difficulty index of 2.58 (very difficult). It is obvious that the sub-aspects of structure and function related to anatomy generally gain low cognitive abilities, meaning that they have a higher level of difficulty, abstraction, and complexity. Hence, it is recommended that these sub-aspects should delivered at higher grades of the elementary school level.

Conceptually, a learning continuum should be organized by considering the grading level, from the lowest to the highest. Knowledge aspects must be developed from the simplest to the most complex, easy to difficult, and concrete to abstract [34]. This principle can be applied to all components of the learning continuum because it is a sequence of knowledge or skills that are built from one level to the next [35]. Initial knowledge or skills serve as the basis for learning other knowledge/skills at the next level, so that they accumulate into cumulative knowledge or skills [34], [36]. The higher the grade or education level, the wider the scope and depth of the material, and the concepts developed by the students also increase because the initial material becomes the foundation for them to uncover the next concepts [37], [38]. According to Australian Curriculum, Assessment and Reporting Authority (ACARA) [39], the learning continuum in the Australian curriculum is also arranged from the simple to more complex elements. The Northwest Evaluation Association (NWEA) [40] also does the same thing on the Rasch Item Test (RIT), where the learning continuum is made from the lowest to the highest level. A learning continuum is managed from simple to complex or from the easiest to the most difficult [35]. This is intended in such ways so that the learning objectives can be achieved effectively based on the students' knowledge and mental development.

The construction of the learning continuum will provide many benefits. As stated by NWEA [40], a learning continuum can help teachers to improve their abilities to provide targeted instruction for individual or group learning. It also has a strategic role in teaching activities, including guiding educators in finding more appropriate teaching materials for their students, sharing resources, planning school curriculum, improving school achievement, monitoring the students' learning progress, and notifying the students' parents about their academic status and progress. According to the European commission [41], the learning continuum can be used as a guide for formal, informal, and non-formal learning activities.

Considering the many advantages of the learning continuum, it is very important to develop it in every aspect of the learning material, including the one in the biology science, as a subject that has been taught from elementary school to college level. The preparation of the learning continuum will greatly facilitate the respective teachers in preparing the learning process so that learning can be maintained in more directed ways effectively and efficiently. This, finally, supports the ultimate goal of education, namely to facilitate learning that enables the students to achieve the expected competency mastery according to their developmental level.

4. CONCLUSION

Based on the results of the research, this study suggests some concluding points. First, teachers' cognitive ability test results can be used as a basis in developing a learning continuum on biology science at the elementary school level, specifically in the aspects of structure and function. Secondly, this study supports the idea, that a learning continuum should be prepared based on the difficulty level of the test items which, at the same time in IRT, shows the cognitive ability values and levels of cognitive processing, starting from lower to higher levels, and the complexity (from simple to most complex) of the structure and function each sub-aspect. Next, the sub-aspects of the materials with higher cognitive ability value, lower difficulty index, lower cognitive processing, and lower complexity category are recommended to be taught at the lower grades of elementary schools. In contrast, sub-aspects with low cognitive ability values, higher difficulty index, higher cognitive processing level, and higher complexity category are recommended to be taught at higher grades of primary education.

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