# Developing True/False Test Sheet Generating System with Diagnosing Basic Cognitive Ability


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**Abstract:** Evaluating students' learning effects is an important issue in educational assessment. A common used assessment tool for estimating what students have learned is test, however, item construction is a time-consuming job. This research designs an Item Generation System which can construct true/false items based on Bloom's Taxonomy automatically. At the end of this research, an item generation system is implemented and used to demonstrate the test sheet construction process. An experiment of the course "Basic Computer Concept" is also executed in the two classes of the university.


## 1. Introduction

There are various methods for assessing students' learning effect. Test is one of the frequently used method for getting feedback of students' learning effect. Traditionally, test usually uses paper and pencil. The Computer-based Testing (CBT) researches began in the 1970s, Lord (1970), Jensema (1974) and other researchers started theoretical structure of a mass-administratered with individually tailored test. The conscientious development and implement of the Computerized Adaptive Test (CAT) starts after 1980s. (Wainer, 2000).

Most of the items in the Computer-based testing environment are usually constructed by the teacher or an expert. How to generate items dynamically and automatically from a well-defined knowledge structure is one of the purposes in this research. Furthermore, this research also applies the cognitive levels of Bloom's Taxonomy(Bloom et al., 1956) and knowledge structure(Solso, 1995) to the Computer-based testing determining to diagnose students' cognitive level. To reach this goal, this research resolves several problems. First, this research enhances the previous research, knowledge map (Kuo et al., 2002), to support different cognitive levels. Second, this research uses the generative grammar, the knowledge map, and transformation rules to generate different cognitive levels items. Last but not least, a simple diagnosing method evaluating students' cognitive level is also introduced in this research.

In Section 2 will introduce the related works about cognitive level and item generation. The transformation strategy for constructing the bloom-based knowledge structure from the textbook and different type item generation will both be illustrated in Section 3. Section 4 shows the generative grammar and transformation rule in this research. The system architecture of the Item Generation System proposed by this research is designed in Section 5. Evaluation method and system experiment will be also described in Section 5. Finally, we will give a little discussion about the summary of this research and some possible future works in Section 6.

## 2. Item Generation and Cognitive levels

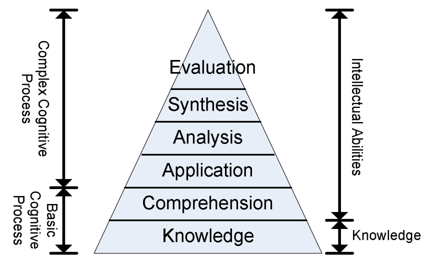



**Figure 1.** The levels of the cognitive domain in Bloom's Taxonomy.

Bloom categorized the educational objectives into cognitive domain, affective domain, and psychomotor domain (Bloom et al., 1956; Krathwohl et al., 1964). The affective domain emphasizes on the feeling and emotion of students' learning; the psychomotor domain is concerning with the manual or physical skills; and, the cognitive domain discusses the knowledge of mental skill. This research mainly focuses on constructing items based on different levels of the cognitive domain. Fig. 1 shows six major levels in the cognitive domain.

**Table 1.** The question types in each cognitive level

| Question type | Knowledge | Comprehension | Application | Analysis | Synthesis | Evaluation |
|---|---|---|---|---|---|---|
| True/false | √ | √ | | | | |
| Matching questions | √ | √ | | | | |
| Multiple-choice | √ | √ | √ | √ | | |
| Short-answer | √ | √ | √ | √ | | |
| Calculation | √ | √ | √ | √ | | |
| Translation | √ | √ | √ | | √ | |
| Essay | √ | √ | √ | √ | √ | √ |
| Comprehension 'Gobbets' | √ | √ | √ | √ | √ | √ |
| Problem based | √ | √ | √ | √ | √ | √ |
| Simulation testing | √ | √ | √ | √ | √ | √ |
| Performance | √ | √ | √ | √ | √ | √ |

Some researchers determined that different cognitive levels can be only examined by some question types. As Table 1 shows, true/false and matching test can only evaluate Knowledge and Comprehension levels; multiple choice, short answer, and calculation can examining higher cognitive levels, such as application and analysis; if teachers want to test synthesis or evaluation level, they will need to use problem based, simulation testing and some other question types to get the result. ( e-Learning Adviser Network, n.d.).

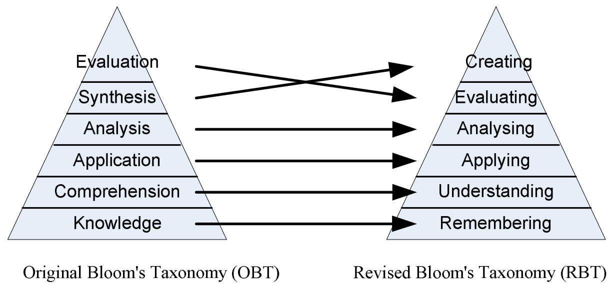



**Figure 2.** The comparison between the original Bloom's Taxonomy and the Revised Bloom's Taxonomy.

Bloom's Taxonomy has already been used for over 30 years to estimate students' cognitive skills. During the 1990's, Anderson and Krathwohl proposed an updating cognitive levels called Revised Bloom's Taxonomy (RBT). Different from the traditional cognitive levels, the noun cognitive level names are turning to the verb ones. Furthermore, the Evaluation level is decreased to the fifth level by adding creating as the highest level. Figure 2 shows this difference of OBT and RBT.

**Table2.** The two-dimensional Taxonomy Table

| **The Knowledge Dimension** | **The Cognitive Process Dimension** | | | | | |
|---|---|---|---|---|---|---|
| | Remember | Understand | Apply | Analyze | Evaluate | Create |
| Factual Knoweldge | List | Summarize | Classify | Order | Rank | Combine |
| Conceptual Knowledge | Describe | Interpret | Experiment | Explain | Assess | Plan |
| Procedural Knowledge | Tabulate | Predict | Calculate | Differentiate | Conclude | Compose |
| Meta-Cognitive Knowledge | Appropriate Use | Execute | Construct | Achieve | Action | Actualize |

Besides the changes of the levels in the cognitive domain, RBT also converts the one-dimensional structure into two-dimensional structure. The new dimension is the knowledge dimension, which is separated into four levels based on the knowledge types a student learned. The four levels of knowledge dimension are (Krathwohl, 2002) factual knowledge, conceptual knowledge, procedural knowledge and meta-cognitive knowledge. The intersection of the knowledge and the cognitive process dimensions form twenty-four cells and present the "Taxonomy Table". This research defines each cell in the Taxonomy Table as students' Cognitive Ability.

There are several researches applying RBT to different domains. Mayer uses RBT as a tool to evaluate students' cognitive process in problem solving (Mayer, 2002). Noble applies RBT to Multiple Intelligence as a planning tool for curriculum differentiation (Noble, 2004). In the other hand, Padmaperuma et al. discuss the possible encountered problems when applying RBT to Engineering Science class (Padmaperuma, et al., 2006).

This research plans to generate items and construct testsheet to diagnose students' cognitive levels about the specific knowledge domain. A test item (marked as $I$) is a unit of measurement and intended to get a response from an examinee for getting their psychological structure (Osterlind, 1989). This research only designs true/false (denoted as $I^{truefalse}$) items for estimating students' cognitive levels. Following the analysis in Table 1, knowledge (or remember) and comprehension (or understand) are the only cognitive levels those types can be examined. To simplify the analysis, the knowledge structure design and item generation method in the following sections only focusing on basic cognitive process (Remember in Figure 1) which are List and Describe regarding procedural and meta-cognitive knowledge currently.

## 3. Cognitive Ability Analysis

The purpose of this research is focusing on designing knowledge structure which presenting the cognitive levels in Bloom's Taxonomy. Most of the sentences in the textbook can be used to represent the concepts and the concept relations. Analyzing the sentences in the text book can be the foundation of knowledge structure construction.

Most of the sentences in learning materials are compound ones. However, the simple sentences are easier to analyzed the concepts and relations in the teaching material. The first step to construct the knowledge structure of the teaching material is to separate the compound sentences to simple ones. Only assertive simple sentences are used to construct knowledge structure. The definition of assertive simple sentence is

$$s_{simple}^{assertive} = (c^{subject}, r, c^{object})$$

$c^{subject}$ means a concept which is defined as the subject of the sentence. The object of the sentence is denoted as $c^{object}$. The relationship between the subject $c^{subject}$ and object $c^{object}$ is noted as $r$. For example: The sentence "Plant has roots" made up of three parts:"Plant","has" and "root". "Plant" is the subject part of the sentence and "root" is the object part of the sentence. The relation between the two concepts is "has".

To clarify relation types, six link types of network (Dansereau, 1978) is used to identify different relation types among the concepts in the sentences. The link type of the concepts can be defined as $l^{type} = \{r_1, r_2, \ldots\}$ ,like $l^{part\text{-}of} = \{$has, contain , have, …$\}$ or $l^{characteristic\text{-}of} = \{$is, can , …$\}$.For example , the sentence "Plant has roots" could will be identified as "part-of" because of the keyword "has".

**Table 3.** Mapping the link types of the assertive sentences to the different RBT cognitive abilities.

| No. | Sentence | Concept(s) | Relation | Link Type | Ability |
|---|---|---|---|---|---|
| 1 | Plant has root | plant, root | has | Part-of | List |
| 2 | Root is vegetative organ | root, vegetative organ | is | Characteristic | Describe |
| 3 | Root can grasp earth | root, grasp earth | can | Characteristic | Describe |

The link type can also be used to identify the sentence cognitive ability. It can correspond to the cognitive abilities, list and describe. And then define these cognitive ability according to the link types in the sentences.

1. List cognitive ability: belongs to factual knowledge and is in the remember cognitive process. Retrieving the major concepts from the brain could be considered as the list cognitive ability. For this reason, the part-of link types which show the basic relation between concepts are considered as the list
2. Describe cognitive ability: is the ability to specify the concept features. Therefore, a sentence which has the characteristic link type is considered as related to the describe cognitive ability.

Table 3 shows three examples of analyzing link type in simple sentences for identifying RBT. The first sentence has relation "has" in the sentence. Based on the previous definition, the word "has" belongs to $l^{part\text{-}of}$ and makes the sentence cognitive ability becomes "list". The second and third example sentence has relation "is" and "can" which belongs to $l^{characteristic}$. According to the second rule defined in this section, these two sentences are defined as "describe" cognitive ability.

| Sentence | Subject | Relation | Object | Link |
|---|---|---|---|---|
| Plant has root | plant | has | root | Part-of |
| Plant has leaf | plant | has | leaf | Part-of |

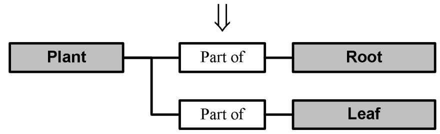
(a)

⇓

| Sentence | Parent Concept ($c^{parent}$) | Relation | Child Concept ($c^{child}$) | Link |
|---|---|---|---|---|
| Plant has root | plant | has | root | Part-of |
| Plant has leaf | plant | has | leaf | Part-of |

(b)

⇓




(c)

**Figure 3.** The generation process of Concept Hierarchy from assertive simple sentence.

The sentences with $l^{part\text{-}of}$ is determined to construct hierarchical relation in Knowledge Map, Concept Hierarchy. Figure 3 demonstrates the generating process of Concept Hierarchy from the simple sentences. The subject part of the sentence is the parent node in the hierarchy structure. On the other hand, the object part is the child node. The link between parent and child node stores the link type of the concept relation.

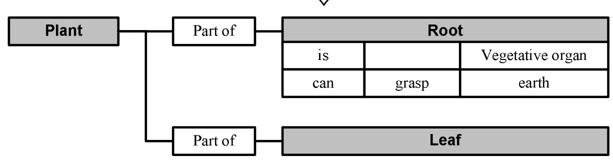
The other types of sentence with $l^{characteristic}$ is used to construct Concept Schema in Knowledge, which showing the attributes of a concept. Figure 4 shows the workflow of decomposing sentence to Concept Schema. The subject part of the sentence is the concept existing in the Concept Hierarchy. The information in the related attributes of the concept comes from the object part of the sentence. When storing the object part in the Concept Schema, the verb part is extracted and stored in the Attribute Action. The remaining part of the object part (the noun part) is defined as the Attribute Name.

| Sentence | Subject | Relation | Object | Link |
|---|---|---|---|---|
| Root is vegetative organ | root | is | vegetative organ | Characteristic |
| Root can grasp earth | root | can | grasp earth | Characteristic |

(a)
⇓

| Sentence | Concept ($c_i$) | Relation Name ($a^{relation\text{-}name}$) | Attribute Action ($a^{attribute\text{-}action}$) | Attribute Name ($a^{attribute\text{-}name}$) | Link |
|---|---|---|---|---|---|
| Root is vegetative organ | root | is | | vegetative organ | Characteristic |
| Root can grasp earth | root | can | grasp | earth | Characteristic |

(b)
⇓




(c)

**Figure 4.** The generation process of Concept Schema from assertive simple sentence.

## 4. Testsheet Generation

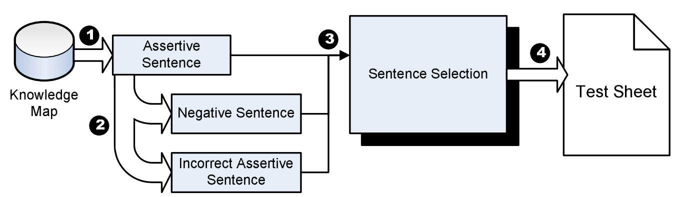



**Figure 5.** The flowchat of testsheet construction

When the Knowledge Map is constructed, the next step is to generate a testsheet with different cognitive level items. Figure 5 shows a flowchart of constructing testsheet from Knowledge Map. In the beginning, the system uses generative grammar (Chomsky, 1957) to construct assertive sentences from Knowledge Map. The assertive sentences can be transformed to negative sentences and incorrect assertive sentences by using transformation rules. After that, one of the sentence type will be selected then put in the testsheet.

### Assertive Sentence Generation

Generative grammar is wildly used for analyzing sentence structure and generating sentences. According to section 3, this research designs one generative grammar for constructing assertive sentences from Knowledge Map, as follows:

$G = (D_N, D_T, S, R)$
$D_N = \{$ Attribute, $l^{part\text{-}of}\}$
$D_T = \{ c^{parent}, c^{child}, c_i, a^{relation\text{-}name}, a^{attribute\text{-}name}, a^{attribute\text{-}action}, a^{attribute\text{-}action(first\_half)}, a^{attribute\text{-}action(later\_half)},$
has, contain, is for, and, 、, or, … }
S = S
R:
(1) $S \rightarrow c^{parent} + l^{part\text{-}of} + c^{child}$
(2) $S \rightarrow c_i +$ Attribute
(3) Attribute $\rightarrow a^{relation\text{-}name} + a^{attribute\text{-}name}$
(4) Attribute $\rightarrow a^{relation\text{-}name} + a^{attribute\text{-}action} + a^{attribute\text{-}name}$
(5) $l^{part\text{-}of} \rightarrow$ has, is, …

Table 4 describes the mapping between the rules in the generative grammar and the cognitive ability.

**Table 4**. The relation between the rules of the component in Knowledge Map in assertive sentence and the rules in the generative grammar.

| Rules in the generative grammar | Description | Corresponding Cognitive Ability |
|---|---|---|
| (1) | The relation between two concepts in Concept Hierarchy. | List |
| (2) | The relation between one concept and one of its attribute in the Concept Schema. | Describe |
| (3) | Connecting the relation name and the attribute name in an attribute in Concept Schema. | Describe |
| (4) | Connecting the relation name, attribute action, and attribute name in the attribute in Concept Schema. | Describe |

**Sentence Transformation**

Assertive sentence can be change to various type of sentence by using transformation rules (denoted as T in this research). Transformation rule of negative sentence ($T_{not}$) is used to transform assertive sentence to negative sentence. The other transformation rule used in this research is used for construct incorrect sentence, which is denoted as $T_{inc}$.

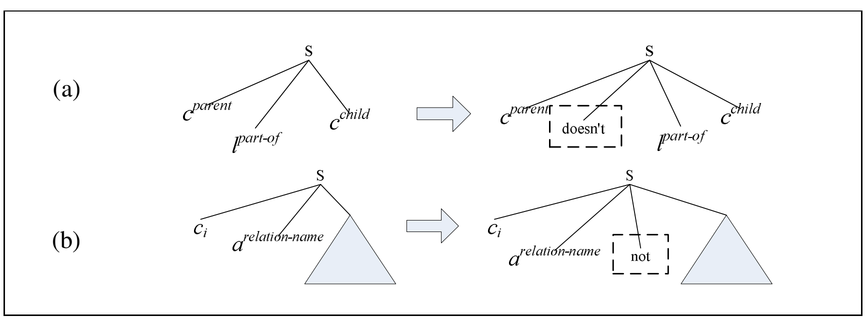
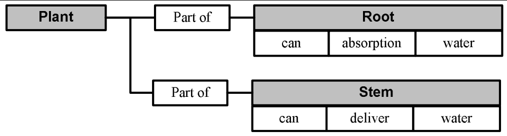


**Figure 6.** Converting two different assertive sentences to negative sentences.

Figure 6 shows the method of how to convert assertive sentences to negative ones. If the assertive sentence is constructed by the (1) rule in the generative grammar, the way to convert the sentence is to add the negative word "doesn't" in front of the word in $l^{part\text{-}of}$ just like Figure 6(a) shows. Figure 6(b) demonstrates that putting the negative word "not" behind the word in $a^{relation\text{-}name}$ can convert the assertive generated by rule (2) in the generative grammar to the negative sentence.




(a)

⇓

| Sentence Type | $c_i$ | $a^{relation\text{-}name}$ | $a^{attribute\text{-}action}$ | $a^{attribute\text{-}name}$ | Sentence |
|---|---|---|---|---|---|
| ✓ | root | can | absorption | water | Root can absorption water |
| ✗ | root | can | deliver | water | Root can deliver water |

(b)

**Figure 7.** Transforming correct sentence to incorrect one.

The way the transform correct sentence to incorrect one used in this research is to find a replaced attribute action in the Concept Schema. Figure 7(a) is a image of partial Knowledge Map. To create an incorrect sentence from the sentence "Root can absorption water", the first step is to analyze the sentence as the second row in Figure 7(b) shows. The next step is to find the replacement of the $a^{relation\text{-}name}$ in the sentence, "absorption". The way to find the replacement is to search another $a^{relation\text{-}name}$ with same $a^{attribute\text{-}name}$ in some other Concept Schema, which is in the "Stem" concept node of Figure 7(a). The last step is to change the correct $a^{relation\text{-}name}$ to the incorrect one, just as the third row of Figure 7(b).

The third step in Figure 5 is to select one of the sentences generated bye generative grammar and transformation rules as the item in the testsheet. When all the concepts and schemas in the Knowledge Map is generated to item, the system creates a testsheet in the last step in Figure 5.

## 5. System and Experiment


**Figure 8.** A snapshot of Knowledge Map

Based on the analysis in the previous sections, an experiment is established and makes an experiment in the "Basic Computer Concept" course in one of the university in Taiwan. There are two classes with 47 and 23 students. The teacher spent 1 hour to choose suitable sentences from the textbook. The researcher also spent 1 hour to analyze the chosen sentences to find out the concepts and relations in the sentences. When the sentences are analyzed, the researcher spent 15 minutes to construct the knowledge structure, Knowledge Map, which can be seen in Figure 8.

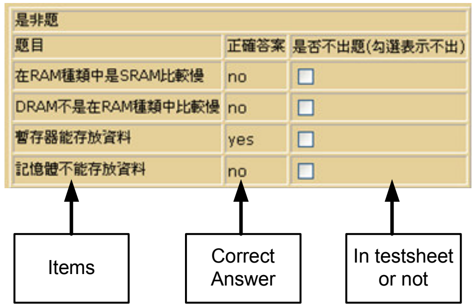



**Figure 9.** Interface for teachers selecting items for the testsheet.

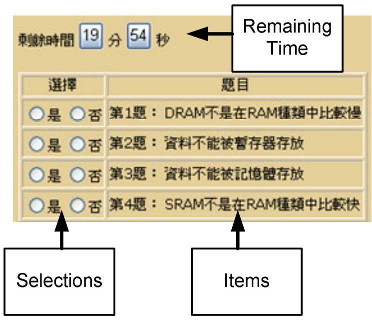



**Figure 10.** Interface for students responding answers.

The Knowledge Map in Figure 8 generates 64 different items. Teachers can use the interface in Figure 9 to decide which item should be existed in the testsheet. When the testsheet is constructed, students can use the interface in Figure 10 to answering the questions.

The entire experiment is executed in the early December. The next step of this research is to analyze the data in this experiment and interview the teacher and students.

## 6. Conclusion and Future Works

This research enhances Knowledge Map to supporting different cognitive levels item generation based on Revised Bloom's Taxonomy. The designed generative grammar generates various sentence types with different cognitive ability. Those sentences can be the true/false items in the testsheet. An experiment system is established in the end of this research and executed an experiment with "Basic Computer Concept" course.

Besides analyzing the experiment data, there are some further works can be discussed in the research. Design other item types, such as multiple question and matching, can be the way to make the testsheet have more variety. Higher cognitive level items construction can gives teachers more information about students' cognitive ability. An efficient way to explain students' cognitive ability according their answer is also a challenge for the future works.

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