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# Development of visual representation competence taxonomy for science teaching and learning

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## Abstract

*Scientific reading and writing typically includes various forms of visual representations. The use of visual representation makes it possible for scientists to develop models and ideas to explain complex phenomena. Visual representation also plays an important role in communicating, learning, and teaching science concept. To provide framework conducive to assess visual representation competence and to devise appropriate educational activities for it, visual representation competence taxonomy (VRC-T) was developed in this study. VRC-T includes two dimensions: the type of visual representation, and the cognitive process of visual representation. The initial categories for each dimension were developed based on literature review. Then validation and revision was made by conducting teachers' workshop and survey to experts. The types of visual representations were grouped into 3 categories (descriptive, procedural, and explanative representations) and the cognitive processes were grouped into 3 categories (interpretation, integration, and construction). The sub categories of each dimension would be explained with examples.*

**Keywords:** *Visual representation, Taxonomy, Type of visual representation, Cognitive process of visual representation;*

## 1. Introduction

Various forms of visual representations such as photographs, diagrams, and graphs are tools that enable scientific discovery and scientific reasoning when scientists conduct the research. For instance, Faraday, the British scientist, expressed the shape of iron powder around the magnet as a 'line of force' and his visual inference played an important role in developing electromagnetic field theory [1]. Today's advanced technologies enabled us to create and utilize a variety of visual representations in science that has not been previously possible (e.g. electron microscope photographs). Visual representations in science can help problem solving, bridge the knowledge gap, and help knowledge construction [2].

In science education, research dealing with visual representations has mainly focused on the topics how to deliver the information efficiently using visual representations. However, recently research emphasizing the students' participation in visualizing process has been increasing [3]. As visual representations can enhance students' scientific reasoning, participation, and communication skills [4], the importance of visual representation competence is being emphasized as the set of scientific skills and practices [5]. However, little empirical research has been done on the effective use of visual representations in the classrooms. Therefore, systemic approach is necessary to explore the purpose and effectiveness of utilizing the visual representations in science classrooms.

Developing a taxonomy focusing on visual representation use in classrooms can be a stepping stone to facilitate effective use of visual representations in science learning and teaching as it can provide a framework for organizing, planning, implementing, and improving the teaching and learning. Bloom's taxonomy, which is a representative educational taxonomy, was introduced in 1956 [6] and has been widely used for decades to design curriculum, set learning objectives, and conduct an assessment. Recently Bloom's taxonomy was revised [7], and also Bloom's digital taxonomy was suggested for teaching and learning with ICT [8].

In this study, taxonomy of visual representation competence was developed for the purpose of promoting the effective use of visual representations in teaching and learning science and providing a platform for systematic science education research.

## 2. Research methods

The initial categories for each dimension were developed based on literature review. Validation and revision was made by conducting teachers' workshop and survey to experts.

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Firstly, the literature review was conducted about three themes: 1) classification of visual representations 2) cognitive theory of visualization process 3) visual representation competence. As a result, the first VRC-T model was developed.
Secondly, the workshop with elementary teachers was conducted for its validation. Taxonomy should be easy and clear enough so that teachers can classify the visual representations and set the learning objectives based on the taxonomy in their practice. Therefore, four in-service teachers classified the visual representations in the science textbooks and wrote the learning objectives based on the first VRC-T model in the workshop. The first model was revised to make a second model reflecting the problems and challenges that we found in the workshop.
Thirdly, 16 typical representations from the elementary science textbooks were selected and some learning objectives corresponding to each cognitive process were stated by the researcher. Seven elementary science education experts were asked to classify the selected visual representations using VRC-T and agreement rate between the researcher and experts was analysed. The experts were also asked to evaluate the appropriateness of learning objectives as a four-point scale. Finally, the third model was made by reflecting the responses from the experts.

## 3. Results

### 3.1 Type of visual representation

Visual representations can be divided into several types according to their characteristics. Moline classified visual representations into simple diagrams, comprehensive diagrams, analytical diagrams, tables, maps, and timelines [9]. In science education research, three types of representation, those are macro, micro and symbolic representations, has been more widely used [10,11,12]. However, Talanquer argued that all knowledge in chemistry cannot be categorized into the triplet and we should be careful to say that understanding macro ideas is easier than understanding micro ideas [13]. Jo et al. categorized the visual representations in the Korean secondary school science textbooks using two -dimensional frameworks. The vertical axis is divided into macro, micro, and symbolic representations according to its abstractness. The horizontal axis is divided into descriptive, explanative, and relational representations according to its purpose [14].
In this study, educational purpose was regarded as the key to categorize visual representation type. So Jo et al.'s descriptive, explanative, and relational representation was used as the basis of initial VRC-T model. The categories were revised and regrouped by conducting teachers' workshop and by analysing survey to experts. Finally, 6 sub-categories were made (Table 1).

**Table 1. Categories of the type of visual representation**

| Category | Sub-category | Definition | Example |
|---|---|---|---|
| A. **Descriptive representation:** Delivering the fact by describing the things or phenomena | Aa. Realistic description | Realistic description of the things or phenomena, external features or internal structures of objects, and behaviour of plants and animals | Appearance of plants and animals, The internal structure of the bulb, cross section of plant stem etc. |
| | Ab. Description using symbols | Using symbols to describe the things or phenomena, external features or internal structures of objects, and behaviour of plants and animals | Electric circuit diagram, Rainfall bar graph, Volcano distribution map using symbol etc. |
| B. **Procedural representation:** Showing the process of doing things or the change over time | Ba. Process of doing things | Describing a set of methods or sequences for performing a task | Procedure of making electromagnet, manual of experimental instruments etc. |
| | Bb. Process of change over time | Describing time and seasonal change or movement of an object | Seasonal constellation, growth of plants and animals, graph of water |

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| | | | temperature change over time etc. |
| C. **Explanative representation:** explaining the cause and regularity of the phenomena | Ca. Explanation of the scientific model | Explaining scientific concepts or principles, hypothetical ideas in order to explain the phenomenon | Water cycle diagram, particle representation of gas volume changes etc. |
| | Cb. Explanation of relationships between the concepts | Explaining concepts using metaphors or relationships, hierarchy and inclusion between concepts | Water flow analogy to electric circuit, plant classification diagram, concept map of light properties etc. |

### 3.2 Cognitive process of visual representation

Some scholars suggested theoretical process of visualization. Burton proposed the visualization process as four stages: 1) a visual perception stage that accepts information from the outside world into the eyes and brain, 2) a visual imaginary stage that recreates the image by processing the information, 3) an integration stage that keeps revising the mental model until it is understood and ready for communication, 4) visual communication or production stage that communicates using the visual presentations [15]. Similarly, Mnuguni argued a three-step visualization process (internalization, conceptualization, and externalization of visual models) [16]. This process involves understanding visual information, processing it in a cognitive structure, and expressing information through a visual model. In his model the visual perception and imaginary stages of Burton were integrated into 'internalization' process. In this study, the cognitive process of visual representation was categorized into three based on those previous models: interpretation, integration, and construction.
Also, the elements of representational competence elements were extracted from the previous studies and regrouped to set the initial cognitive processes. The sub-categories were revised by reflecting the teachers' workshop results and experts' responses to the survey and finally 6 sub-categories were made (See Table 2).

**Table 2. Categories of the cognitive process of visual representation**

| Category | Sub-category | Key predicates |
|---|---|---|
| **1. Interpretation of VR:** Interpreting the information and meaning presented in the given visual representation. | 1.1 Interpreting Explicit Information | • Identifying symbol or value<br>• Reading symbol or value |
| | 1.2 Interpreting conceptual information | • Interpolating/Extrapolating (from a graph)<br>• Interpreting the meaning by making inference such as predicting, generalizing, and concluding<br>• Interpreting through scientific concepts and terms |
| **2. Integration of VR:** Evaluating or transforming the given visual representations by linking them with prior knowledge, concepts, and experiences | 2.1. Transforming (across various forms and situations) | • Transforming the given representation into a different form<br>• Applying the given representation to similar situation<br>• Matching between different forms of representations showing the same information |
| | 2.2. Evaluating the appropriateness | • Selecting the proper one<br>• Justifying the use of the specific representation<br>• Criticizing the inadequate expression or use of the representation<br>• Understanding that scientific representation is not always the mirror of reality. (nature of |

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|---|---|---|
| | | representation) |
| **3. Construction of VR:**<br>Constructing visual representations to show the observed features and scientific ideas. | 3.1 Constructing representations based on senses, rules, and information | • Drawing the features of observed phenomena or objects<br>• Making a map of location or distribution based on the given information<br>• Using the scientific symbols according to the rules (e.g. arrow indicating force) |
| | 3.2 Constructing representations based on reasoning | • Illustrating scientific concept or principle<br>• Drawing a concept map or hierarchical chart to present the relations between concepts<br>• Drawing/Making a visual model to present one's scientific idea (hypothesis) and use it to explain and to predict the phenomenon |

## 4. Conclusion

This study developed a visual representation competence taxonomy (VRC-T) that includes types and cognitive process of visual representation. VRC-T could help teachers and researchers to clarify the learning objectives with visual representations, and accordingly assess the learning outcomes more easily. More efforts need to be made to validate and refine the VRC-T. For instance, hierarchy in cognitive processes needs to be explored and confirmed by follow-up studies. Also, as the validation process such as workshop was conducted by elementary teachers only, the validity for secondary science education needs to be confirmed.

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